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ELECTRIC TRACTION

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J. H. RIDER

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THE SPECIALISTS' SERIES

ELECTRIC TRACTION

A PRACTICAL HANDBOOK ON THE APPLICATION OF ELECTRICITY AS A LOCOMOTIVE POWER

BY

JOHN HALL RIDER

Chief Electrical Engineer, London County Council Tramways; Member of the Institution of Civil Engineers; Member of Council of the Institution of Electrical Engineers; Member of the Institution of Mechanical Engineers; Past President of the Incorporated Municipal Electrical Association

WITH 194 ILLUSTRATIONS

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PREFACE

In this book the Author has endeavoured to deal with the subject of Electric Traction from a practical standpoint, and mathematics have only been introduced where necessary, and then only in a very simple form. Detailed descriptions of various traction undertakings have not been given, as what is good practice in one case is not necessarily so in another.

The diagrams given in Figs. 2, 33, 37, and 58 are necessarily on too small a scale to be of much value for working reference. But, if reproduced by the reader on a larger scale, and with more subdivisions, they will prove of great assistance in making rapid calculations.

The Author's best thanks are due to Messrs. R. W. Blackwell & Co., Ld., J. G. Brill & Co., the British Electric Car Co., Ld., the British Schuckert Electric Co., Ld., the British Westinghouse Electric and Manufacturing Co., Ld., Mr. A. R. Dayson, Messrs. Dick, Kerr & Co., Ld., Mr. A. C. Eborall, the Electrician Printing and Publishing Co., Ld., Messrs. Elliott Bros., Ld., Ferranti, Ld., the Institution of Electrical Engineers, the Institution of Mechanical Engineers, Mr. T. A. Locke, Mr. E. G. Okell, Mr. W. Press, the *Tramway and Railway World*, and the Tudor Accumulator Co., Ld., for the use of blocks, drawings, or photographs.

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J. H. R.

The Lindens, 96 *Herne Hill,*
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LIST OF SYMBOLS USED

A = Area in sq. inches.
C = Radius of curve in feet.
D = Distance travelled in feet.
d = Diameter in inches.
F = Tractive force in lbs. per ton.
G = Gradient, or distance in feet for vertical rise of 1 foot.
g = 32·2, or acceleration due to gravity.
H.P. = Horse-power.
I = Induction factor.
K = Energy in foot-pounds.
k = A constant.
K.W. = Output in kilowatts.
L = Length of double journey in miles.
l = Length in inches.
M = Speed in miles per hour.
m = Mass.
N = Width of gauge in feet.
R = Revolutions per minute.
S = Speed in feet per minute.
s = Minutes apart of cars, or headway.
T = Torque in lbs. pull, at 1 foot radius.
t = Time in minutes.
v = Terminal velocity in feet per second.
W = Weight in tons.
w = Weight in lbs.

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ELECTRIC TRACTION

CHAPTER I.

INTRODUCTION.

General Remarks—Principle of Dynamo and Motor—Torque—Horse-Power—Efficiency—Tractive Resistance and Effort—H.P. at uniform speed on level road—Gradients—H.P. at uniform speed on Gradients—H.P. at varying speed—Acceleration—Examples in finding H.P.—Starting a car from rest—Starting Current—Varying Power required—Average Power—Methods of economizing Power—Fixed stopping-places—Cars required for given service—Trailer Cars—Car Mile—Passenger Mile—System of Electric Traction—Company *versus* Local Authority.

General Remarks.—The latter part of the nineteenth century saw many wonderful developments and changes, but none more wonderful than the rapid growth of the electrical industry, and the application of electricity to almost every part of our social and business life. Owing possibly to national characteristics, and to the absence of legislative restrictions, the greatest advances have no doubt been made in America. But, while progress has been slower in this country, it has been none the less sure.

In the early days, the use of electricity was practically confined to telegraphic purposes, but, with the advent of the dynamo, Electrical Engineering may be said to have

begun. So long as electricity could only be produced by the consumption of zinc in primary batteries, so long was its use in large quantities out of the question, on account of the cost. But, when the transformation of Mechanical into Electrical energy, through the medium of the dynamo, was an accomplished fact, then the cheap production of electricity became possible.

It did not take long to discover that the dynamo was a reversible machine, *i. e.* that if supplied with mechanical power it would generate electricity, and, if supplied with electricity, it would give out mechanical power. It is not quite clear as to how this was found out, whether by accident or by deduction, but, once discovered, the development of the dynamo was speedily followed by that of the motor. An enormous field was at once opened up, and, by reason of the remarkable efficiencies of both dynamos and motors as converters of energy, the possibility of the transmission of power by electricity was quickly recognized.

Electric Traction is destined to form not the least important part of this subject, and, although it may be many years before our main railway lines are entirely worked by it, yet the near future will see, not only most of the existing horse tramways converted into electrical ones, but also the establishment of a number of electrically equipped light railways, connecting our large towns.

Principle of Dynamo and Motor.—Both the dynamo electric machine, and the electric motor, depend, in principle, upon the correct disposition of three things, viz.—(1) magnetism, (2) conductors (usually coils of copper wire), and (3) motion, and in both cases the conductors are usually made to rotate within the magnetic field. In the case of the dynamo, the rotation is accomplished by

mechanical means, in the shape of a steam-engine, or other prime mover, and a current of electricity is set up in the conductors, in consequence of the motion.* In the case of the motor, the rotation is produced by a current of electricity being sent through the conductors, from an outside source, and mechanical power is obtained as a result. Every dynamo can be used as a motor, and every motor as a dynamo, although not necessarily a self-exciting one.

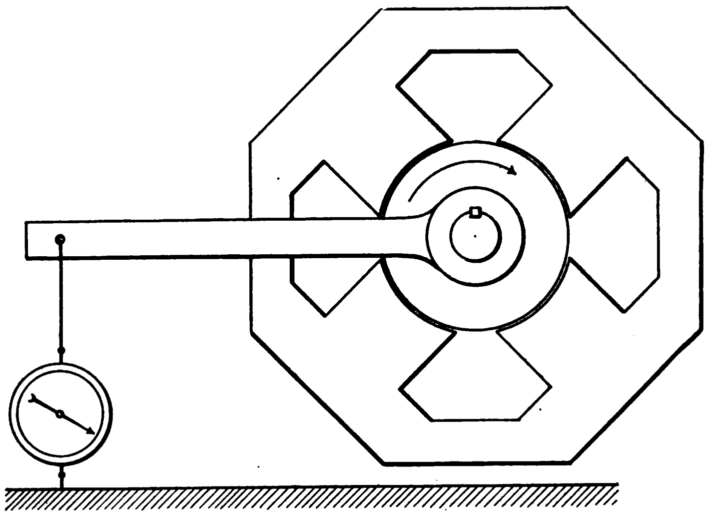
All the varied forms of dynamos and motors in existence are based upon these main facts, the differences in their detail being caused by different arrangement, or proportion of parts, to obtain either greater efficiency, or a greater output for a given weight of materials, and also, in many cases, merely to obtain a design a little different from that of competing manufacturers.

While it is true that, in every commercial scheme for the supply of electricity, the dynamo is indispensable, yet its direct use is not necessary in order to produce rotation of the motor. Storage batteries, or accumulators, may be, and often are, used as the immediate source of the electric supply. But, without the motor, electric transmission of power is impossible. It is the heart and soul of every electric traction system, and upon its efficiency and reliability the success of the whole depends. The generating station, supplying a large number of motors in various parts of a district, can be equipped with spare plant, ready for use in case of accident to the running machinery. But it would be impracticable to have a stand-by motor ready in every case.

* This is correct in a general sense only. For a current to flow the external circuit must be closed. An electrical pressure (E.M.F.) is, however, set up in any case.

Torque.—Every electric motor rotates by reason of the pull set up between the magnetism of the fixed part (generally the "field magnets"), and the magnetism of the revolving part (generally the "armature"). We are, therefore, enabled to measure the power of any motor, by knowing the value of this "pull," and also the speed at

Fig. 1.



EXPERIMENT FOR FINDING TORQUE.

which the motor runs. The pull, or "turning moment," or "torque," as it is generally termed, can be measured in "pound-feet," or lbs. acting at a radius of 1 ft. It may be experimentally obtained for any motor, by fixing a lever to its shaft, and connecting a spring-balance at any distance from the centre, as shown in Fig. 1.

On passing the ordinary working current through the motor, the pull will be indicated upon the spring-balance.

This pull, in pounds, multiplied by the distance in feet from the centre of the motor-shaft, will give the "torque." If the magnetism of the field magnets be a constant, it will be found that the torque will be simply proportional to the current passed through the armature.

Horse-Power.—It will be noticed in this experiment, that, although the full torque may be exerted, yet the motor is doing no work, because it is not rotating.

Torque is therefore entirely independent of speed of rotation, and will not be altered, however fast the motor runs, provided the original conditions of field and current strength be maintained. But the speed is an important factor in determining the horse-power, or rate of doing work, of the motor. Knowing the torque and the speed, we are enabled to find the H. P. by the simple formula:—

$$\text{H. P. of motor} = \frac{2\,\pi\,T\,R}{33{,}000} \qquad (1)$$

Where T = Torque in pounds pull at 1 ft. radius.
R = Revolutions per minute.

As an example of the practical application of this, we may take the case of an electric tramcar having two motors geared to wheels 30 in. diameter. If each motor be capable of developing a pull of 1,000 lbs. at the periphery of the car wheels, when the car is travelling at a speed of eight miles per hour, what is the effective H. P. of each motor?

Here the radius at which the pull is acting is $\frac{30}{2}$ inches, or 1·25 ft., and the torque is, therefore, 1,000 lbs. × 1·25 ft. = 1,250 pound-feet. In order to travel at the rate of eight miles per hour, a wheel 30 in. in diameter must make 89·6 revolutions per minute, and so we have—

$$\text{H. P.} = \frac{2 \times 3{\cdot}14 \times 1250 \times 89{\cdot}6}{33{,}000} = 21{\cdot}3 \text{ H. P. for each motor.}$$

The H. P. obtained by this calculation is the "effective," or "brake," and does not represent either the whole power given to the motor, from the source of the electrical supply, or even the whole of the power exerted by the motor.

The total power is divided up somewhat as follows:—

ANALYSIS OF LOSSES IN SINGLE-GEARED TRAMWAY MOTOR.

- **Power supplied to motor (100)**
  - **Power available at motor-shaft (80)**
    - **Lost in Bearing friction and gearing (5)**
    - **Effective power at periphery of Car Wheels (75)**
  - **Power wasted in motor (20)**
    - **Bearing and other friction (2)**
    - **Hysteresis (1)**
    - **Eddy currents (1)**
    - **Resistance of Conductors (16)**

The relative values of the different items will vary considerably, according to the speed and output, but, in a modern car-motor, running at full speed and power, they would be about as given.

In order to obtain lightness, it is usual to make motors for traction work with relatively much more powerful armatures, than in motors for other purposes. The result is shown above, in the proportionally large loss due to the resistance of the conductors.

Efficiency.—Knowing the values of the various losses, we are enabled to determine the efficiency of the motor, and, in so doing, we must distinguish between (1) commercial efficiency, and (2) electrical efficiency.

To the user of the motor the "commercial efficiency" is of the first importance. It is the ratio between the effective mechanical power of the motor, after taking into account every loss, and the total electrical power supplied to the motor. In the above example it would be 75%, the

losses due to the gearing being debited to the motor. Had the motor been mounted direct upon the car-axle, so that gearing was not required, the commercial efficiency would have been 80%, all other things being the same.

The "electrical efficiency" is the ratio between the electrical power actually used in driving the motor, and the total electrical power supplied. In the above example it is 84%.

A motor is often spoken of as having a certain efficiency, as if such efficiency were a property of the motor, instead of depending upon the speed and output. The best motor ever made has a commercial efficiency of 0% when running light, as all the power supplied is being used to drive the motor itself.

So far we have only considered the methods of finding the efficiencies and power of electric motors, but, in order to be able to select motors of the correct size for any tramway service, it will be necessary to know how much power each car will require. The power is required for three things, viz.—(1) the tractive resistance, (2) the inclination of the road, or the gradient, and (3) the acceleration.

Tractive Resistance and Effort.—Tractive resistance is the resistance offered to a car by the roughness, and the state of the surface, of the rails, and also by wind and other friction. The power required to overcome tractive resistance is called "tractive force," or "tractive effort," or sometimes the "tractive coefficient," and is generally expressed in pounds per ton of the gross weight of the car. This expression means that a corresponding pull, or tractive effort, has to be exerted at the periphery of the car wheels, in order to overcome the tractive resistance. In the case of a horse-car, or a car hauled by any external

force, the pull would, of course, be applied to the draw-bar, and not to the wheels. The tractive resistance varies considerably with the condition of the rails. With a car running at uniform speed, on a level road, the tractive effort may be as low as 15 lbs. per ton, with exceptionally clean and smooth rails, or as high as 50 lbs. per ton, with dirty clogged rails, or on curves. The average is generally taken as 30 lbs. per ton.

H. P. at uniform speed on level road.—We may now find the horse-power necessary to propel a car at uniform speed, upon a straight and level track. The total pull in pounds, multiplied by the number of feet travelled per minute, will give foot-pounds per minute, and this, divided by 33,000, will give the horse-power. It may be simply expressed as—

$$\text{H. P. on level road} = \frac{F.\,W.\,D.}{33{,}000\,t} \qquad (2)$$

Where F = Tractive force in pounds per ton.
W = Weight of car and passengers in tons.
D = Distance travelled in feet.
t = Time in minutes.

Gradients.—Unfortunately for tramway purposes, the great majority of our roads are anything but level. The gradients make no difference in descending the hills, except to call for reliable brakes, because gravity provides the propelling power. But, as the cars also have to ascend the hills, against the force of gravity, a corresponding increase in the power of the motor is required.

The inclination of the road, or the gradient, is generally expressed by stating the number of feet travelled for a vertical rise of 1 ft. Thus, a gradient of 1 in 20 means, that for every 20 ft. travelled, the car rises 1 ft. Sometimes gradients are given in percentages. Thus, a rise of

1 in 20 would be a 5% gradient, of 1 in 30 a 3·3% gradient, and so on.

The following table gives a ready comparison between the two methods of expressing gradients:—

Table I.—COMPARISON OF GRADIENTS.

1 in	% Gradient.		1 in
100	1·0	1·0	100
90	1·11	1·5	66·6
80	1·25	2·0	50
70	1·45	2·5	40
60	1·66	3·0	33·3
50	2·0	3·5	28·6
40	2·5	4·0	25
30	3·33	4·5	22·2
25	4·0	5·0	20
20	5·0	6·0	16·6
15	6·6	7·0	14·3
12	8·3	8·0	12·5
10	10·0	9·0	11·1
8	12·5	10·0	10

H. P. at uniform speed on Gradients.—To find the power required to propel a car, at uniform speed, up an incline, we must first ascertain the power necessary for a level road, then the power for raising the car against the force of gravity, and add the two together. Knowing the gradient, and the distance travelled by the car in a certain time, we are enabled to find the number of feet of vertical rise per minute, which, multiplied by the gross weight of the car in lbs., will give the foot-pounds per minute against gravity, and, to obtain the horse-power, we only have to divide by 33,000. Thus—

$$\text{H. P. against gravity} = \frac{\frac{D}{G} w}{33{,}000\, t} \qquad (3)$$

Where D = Total distance travelled in feet.
w = Weight of car and passengers in pounds.
G = Distance travelled in feet for a vertical rise of 1 ft.
t = Time in minutes.

H. P. at varying speed.—The two preceding formulæ, if used respectively to find the horse-power necessary to overcome tractive resistance, and to overcome gravity, during a period when the speed of the car is *not* uniform, will give us the *mean* horse-power, and not the maximum.

Accelerating.—In starting a car from rest, or in increasing its speed above that at which it was previously travelling, a certain amount of energy is stored up, depending upon the mass of the car, and upon the acceleration, or rate of change of the velocity. The amount of energy stored in foot-pounds is equal to—

$$K = \tfrac{1}{2} m v^2 \tag{4}$$

Where K = Energy in foot-pounds.
m = Mass * of the car.
v = *Terminal* velocity in feet per second.

To maintain constant acceleration, it will be necessary to do work at a certain rate, depending upon the time the acceleration continues. The rate of doing work may be expressed—

$$\text{Rate of doing work in foot-pounds per minute} = \frac{K}{t} \text{ or } \frac{\tfrac{1}{2} m v^2}{t} \tag{5}$$

* Mass is the *quantity* of matter in a body. In the British Isles it is the weight of a body in pounds, divided by 32·2. The weight of a body depends upon its location in the universe. A pound as measured in London would weigh 2·67 lb. on the planet Jupiter, and would weigh hardly anything near the centre of the earth, although its *mass* would always be the same. Therefore, to find the mass of a body, we must divide its weight in pounds by a number representing the acceleration due to gravity at the various places. In this country that number is 32·2.

Where t = Time in minutes during which acceleration continues.

And the horse-power may then be obtained by dividing by 33,000.

Examples in finding H. P.—We are now in a position to determine the horse-power necessary to drive a car, under any condition of work, whether upon the level road, or ascending an incline, and whether running at uniform speed, or when accelerating. A few practical examples, in illustration, will not be out of place.

We will take the case of a car weighing, with passengers, eight tons, and running as follows, viz.—

(*a*) Starting from rest upon a level road, and attaining a speed of eight miles per hour in half-a-minute.

(*b*) The same as (*a*), but upon a rising gradient of 1 in 15.

(*c*) Running at a uniform speed of eight miles per hour upon the level.

(*d*) The same as (*c*), but upon a rising gradient of 1 in 15.

and find the maximum horse-power necessary in each case.

In (*a*) we shall have to take into account both the tractive resistance and the acceleration. The tractive effort, or pull necessary to overcome the tractive resistance, may be assumed to be 30 lbs. per ton, and the speed of the car will have increased from nothing up to eight miles per hour in the half-minute. As the horse-power depends upon the speed, we must take the maximum speed during the half-minute, in order to find the maximum horse-power. The highest speed is eight miles per hour, or equal to 352 ft. per half-minute, although the actual

distance travelled by the car will have been only 176 ft. in that time. The horse-power, necessary to overcome tractive resistance, will therefore be—

$$\frac{30 \times 8 \times 352}{33{,}000 \times \frac{1}{2}} = 5{\cdot}1 \text{ H. P.}$$

The mass of the car will be $\dfrac{8 \times 2{,}240}{32{\cdot}2} = 556$, and the velocity, at the end of the half-minute, eight miles per hour, or 11·7 ft. per second. The horse-power necessary for the acceleration will therefore be—

$$\frac{\frac{1}{2} \times 556 \times (11{\cdot}7)^2}{33{,}000 \times \frac{1}{2}} = 2{\cdot}3 \text{ H. P.}$$

The total power necessary in (*a*) will thus be $5{\cdot}1 + 2{\cdot}3 = 7{\cdot}4$ horse-power.

To find the power in case (*b*), we shall simply have to add, to the above, the power required to raise the car against the force of gravity. Here, again, the horse-power depends upon the speed, and although the car only rises $\left(\frac{176}{15}\right)$ 11·7 ft. during the half-minute, yet, when the speed has reached eight miles per hour, the car is rising at the rate of $\left(\frac{352}{15}\right)$ 23·4 ft. per half-minute, and at that moment the rate of doing work is at a maximum. The horse-power, necessary to overcome gravity, will therefore be—

$$\frac{\frac{352}{15} \times 8 \times 2240}{33{,}000 \times \frac{1}{2}} = 25{\cdot}4 \text{ H. P.}$$

The total power necessary in (*b*) will thus be $7{\cdot}4 + 25{\cdot}4 = 32{\cdot}8$ horse-power.

In (*c*) the tractive resistance, only, comes into the calculation, as there is neither acceleration nor gravity to consider. Since the speed is uniform at eight miles per hour, the car will travel 704 ft. in one minute, and, in order to overcome tractive resistance, we have to exert—

$$\frac{30 \times 8 \times 704}{33{,}000 \times 1} = 5{\cdot}1 \text{ H. P.}$$

To find the power in case (*d*), we shall have to add to (*c*) the power required to raise the car against the force of gravity. As the speed is uniform, this will be—

$$\frac{\frac{704}{15} \times 8 \times 2240}{33{,}000 \times 1} = 25{\cdot}4 \text{ H. P.}$$

The total power necessary in (*d*) will thus be $5{\cdot}1 + 25{\cdot}4 = 30{\cdot}5$ horse-power.

The powers, obtained in the above examples, are those actually exerted at the peripheries of the car wheels. In order to find the electrical power which has to be *delivered to the car* in either case, we must know the commercial efficiencies of the motors under the different conditions. Then—

$$\frac{\text{H. P. exerted at car wheels} \times 100}{\text{Commercial efficiency per cent.}} = \text{H. P. delivered to motor.}$$

When there is more than one motor on a car, each motor would only have to deal with its proportion of the total load.

In working out the powers and speeds of cars and motors, it is often convenient to know the speed, both in miles per hour, and in feet per minute, and per second. The following table will be useful in this respect :—

Table 2.—TABLE OF SPEEDS.

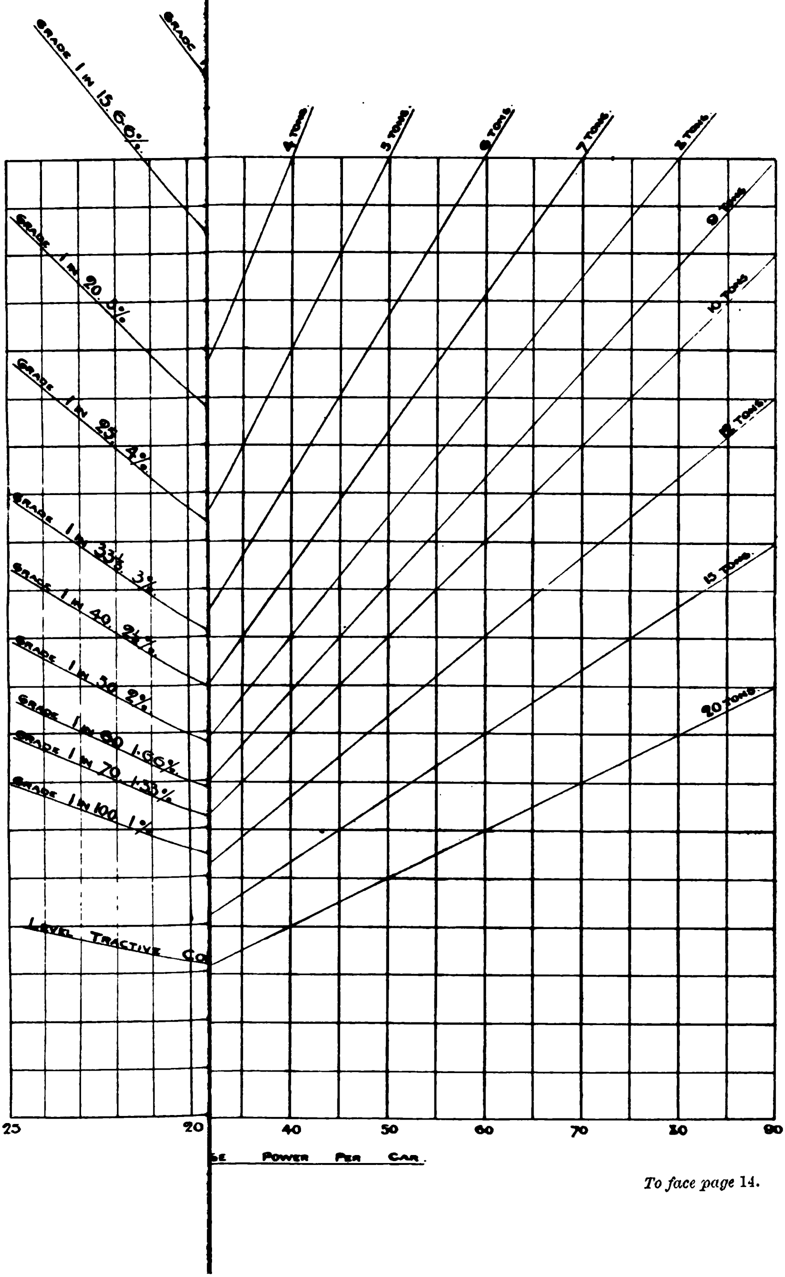
Miles per hour.	Feet per Minute.	Feet per Second.
1	88	1·46
2	176	2·93
3	264	4·4
4	352	5·86
5	440	7·33
6	528	8·8
7	616	10·26
8	704	11·73
9	792	13·2
10	880	14·66
11	968	16·13
12	1056	17·6
13	1144	19·06
14	1232	20·53
15	1320	22·0
16	1408	23·46
18	1584	26·4
20	1760	29·33
25	2200	36·66
30	2640	44·0

The diagram, shown in Fig. 2, will enable us to determine, without calculation, the horse-power required for any car, at any speed, and on any gradient.

To illustrate its use, we will take the case of a car, weighing 12 tons, and running at 10 miles per hour on (1) the level, and (2) on a gradient of 1 in 40.

First, on the level. Find the intersection of the vertical line through 10 miles per hour and the power line for a level track, to the left of the diagram. This gives 0·8 H. P. per ton. Continue horizontally to the right of the diagram, to meet the line corresponding to a 12 ton car. This will give 9·5 H. P.

Second, on a gradient of 1 in 40. The H. P. is found in exactly the same manner, and proves to be 27·2 H. P.



To face page 14.

The right-hand portion of the diagram is really a graphical multiplication table.

Starting a Car from rest.—So far we have said nothing about the force necessary to start a car from a position of rest, and it is here that the distinction between pull (or torque) and power must be thoroughly understood. Power is the *rate* of doing work, or work done in a certain time, and it requires motion. Pull, or torque, signifies a force acting in a certain direction, and, as we saw from the experiment shown in Fig. 1, we may have a torque without any motion, and, therefore, without doing any work. In order to start a car from rest, we have to exert a considerably greater pull than is required to keep it moving, after it has once started. But, however great the pull, until the car has moved, no work has been done, and the H. P. is therefore *nil*. This may seem paradoxical, when we remember that it requires probably several horses to start a car, and that they have to pull very hard to move it, much harder than they afterwards have to pull to keep it moving. But, to pull is not necessarily to do work, unless the body pulled be actually moved.

Starting Current.—Therefore, to start a car, the motors have to exert a considerable torque, in order to overcome the *statical* friction, the torque being produced by the current passing through the armature and field magnets. This starting current may often be from three to four times as great as the normal working current, and, as the supply of electricity to a tramway system is generally carried out at a constant pressure, it means a large amount of power being taken for a short time from the supply mains, although the motors themselves may be doing little work. A part of this power is wasted in

the regulating resistances, as, until the motors begin to revolve, they have no back E. M. F.

The more cars there are running, the less is the heavy starting current felt at the generating station, as it is very improbable that all the cars would be starting at the same instant, and therefore the starting current taken by any car would bear a smaller proportion to the total output, than when only a few cars were on the line. The means which have been adopted to reduce the starting current on individual cars are explained, in detail, in Chaps. V. and VI., when considering motors and controllers.

Varying Power required.—It will be seen that, even on level roads, the amount of power taken by a car will vary largely. The continual stopping to take up passengers, the starting again, the slowing down to clear vehicles, or pedestrians, crossing the track, and numerous other causes, will prevent a constant speed being maintained for any appreciable length of time. On a hilly route, the variation will be much worse, because, while the maximum power will be required in ascending the gradients, in descending no power at all will be needed.

Average Power.—It would not be correct to assume, because the cars take no power in running down a hill, that this would make up for the extra power taken in climbing the same hill, on the return journey, and that, therefore, the average power would be about the same as on a level road. It will be seen, from the examples (*c*) and (*d*), previously given, that while a car takes 5·1 H. P. on the level at a certain speed, it requires 30·5 H. P. on a gradient of 1 in 15 at the same speed, or about six times as much, being an increase on the average power of about three times. In fact, other conditions being equal, the average power required will be greater, on any road having

a gradient steeper than about 1 in 250, than on a level road.

Experience has shown that an electric car can be propelled, at an average speed of about eight miles per hour, on moderately easy roads, with an expenditure of electrical energy equal to about 1 Board of Trade unit per mile. As 1 B. T. unit is 1,000 watts for one hour, this would mean eight units per hour, or an *average* rate of about 10½ H. P. On level roads this figure could be much reduced, while on heavy gradients it would have to be increased.

Methods of Economizing Power.—As the power taken from the supply mains has to be paid for, in one way or another, it is most essential, for the economical working of any electrical tramway system, that all those items, which tend to increase the power taken, should be most carefully watched. The tractive resistance should be kept at a minimum, by keeping the rails properly cleaned, going over them several times a day if necessary, and by seeing that all the running gear of the cars is in good condition, and properly lubricated. The motor-men should be most carefully instructed in the use of the controller, particularly in starting and accelerating a car, and premiums should be offered to those men who drive their cars with the least consumption of energy. And, lastly, but by no means least in importance, fixed stopping-places should be decided upon, at which points only the cars would stop, to pick up or set down passengers.

Fixed Stopping-places.—These stopping-places should be fairly easy to arrange, on any tramway route, and may be of two kinds, viz.—(1) places at which all cars would stop, and (2) places at which cars would only stop if required. The former would of course be at promi-

nent street junctions, averaging say 220 yards apart, and the latter at intermediate points, not less than 100 yards apart. Stopping a car, even once every 100 yards, would be far preferable to what often occurs, when there are no stopping-places, and where a car may sometimes be hailed a dozen times in that distance.

To the tramway management fixed stopping-places are an absolute necessity, if schedule time is to be maintained, and if the consumption of electrical energy is to be kept at a minimum. Once properly understood by the public, there would be no difficulty whatever in working the system, as intending passengers would naturally walk to, and wait at, the nearest stopping-place, instead of standing anywhere along the street. In fact, the saving of time alone, on a journey, would be such as to appeal to the good sense of all.

A possible objection to the system of fixed stopping-places is, that intending passengers might often miss a car, through not having arrived at a stopping-place until the car had just started off. But a fundamental rule for any successful electric, or other tramway, is, that a frequent service must be maintained, so frequent, in fact, that published time-tables are quite unnecessary, the public knowing that, if they miss one car, they will be able to take another in a very few minutes. A rapid and frequent service will create its own traffic, and will often make a previously unsuccessful line pay.

It is essential that passengers should not be allowed to enter or leave a car, except at a stopping-place, at any rate without being individually warned of the danger of doing so. The average speed of an electric car is, perhaps, twice as great as that of a horse car, and, owing to the smoothness of the motion, the greater speed is not so

apparent. Many passengers are in the habit of entering and leaving horse cars when in motion, and, at horse car speed, there is no difficulty whatever in so doing. But with an electric car it is not safe, and the practice should be discouraged.

One result of a good electric tramway system, running into the suburbs of any city or large town, is seen in the growth of residential property, and the rise in the value of land in the neighbourhood.

Cars required for given service.—To increase the frequency of any service, it is of course necessary to put more cars upon the lines, and it is very convenient to be able to make a rapid calculation, as to how many cars would be required for any given service, and upon any section. The following simple formula is applicable in any case—

$$\text{No. of cars required} = \frac{60 \times L}{s \times M} \tag{6}$$

Where L = Length of double journey in miles.
s = Minutes apart of cars, or service.
M = Average speed of cars in miles per hour.

Trailer Cars.—An important advantage, resulting from the use of electric traction on our tramways, is, that it is not necessary to increase the frequency of the service during busy periods of the day, in order to cope with the extra traffic at those times. Trailer cars may be used instead, coupled to the rear of each motor car, thus practically doubling the passenger accommodation when required.

Car Mile.—In comparing, or quoting, the running costs of any lines, it is usual to employ the term "car mile" as the basis. For instance, we speak of horse traction as costing 10*d.* per car mile, and of electric traction as

costing 5*d*. per car-mile, and so on. If all cars, throughout the country, had the same seating capacity, the comparisons, so made, would be reliable. But, when we find some cars capable of carrying only twenty-four, and others nearly one hundred passengers, and when a motor car can have a trailer temporarily attached, it will be seen that the term "car mile" is about as unsatisfactory as could be used. The question may well be asked, "What is a car mile?" "Ton mile" has been suggested as a better unit, but as the weights of cars vary, perhaps, even more widely than their carrying capacities, this is no improvement.

Passenger Mile.—In the author's opinion "passenger capacity mile" or "passenger mile" is the correct unit to employ, and for the following reasons, viz.—(1) The direct object of any tramway undertaking is to convey passengers, and cars are run only as a means to this end. (2) It would enable a direct comparison to be made between the cost of providing accommodation for a passenger for one mile, and the fare charged for that distance. (3) It would enable reliable comparisons to be made between the cost of running, in various towns, where cars of different carrying capacities are used.

One result of the use of "passenger mile" as the unit, instead of "car mile," would be to show how inefficient and costly small cars were as compared to large ones. Town A, for example, congratulates itself that its cost per car mile is, say, only 6*d*., while in Town B the cost is, say, 8*d*. But, since the cars in B will carry twice as many passengers as the cars in A, the cost per "passenger mile" would show the actual state of things.

Systems of Electric Traction.—In order to maintain any vehicle in a state of motion, it must be kept in constant

connection with the source of the propelling power. In the case of horse traction, the horse is harnessed to the car; in the case of cable traction, the car is hauled along by gripping the moving cable; while in the case of electric traction we have the choice of several methods. We may either carry the source of power on the car itself, in the shape of accumulators, which have to be periodically taken to the generating station for the purpose of recharging. Or we may maintain connection with the generating plant, through the medium of a sliding or rolling contact with bare conductors, fixed near the track. These conductors may be either overhead or underground. The motors, gearing, controlling apparatus, and generating plant, may be practically identical in any case.

The various systems of electric traction are, therefore, simply different methods of establishing communication between the moving vehicle and the fixed power station. They are known as—

(1) The overhead, or trolley, system.
(2) The underground, or conduit, system.
(3) The surface contact system.
(4) The accumulator system.
(5) The third rail system.
(6) Combinations of either of the above systems.

These systems are described in detail in the following chapters, and it will be seen, that while the overhead system is the most widely adopted, and, from a commercial standpoint, is the most economical, yet the other systems have each their peculiar advantages, which should be taken into consideration, before deciding upon the one most suitable for any particular locality.

Company *versus* Local Authority.—A question of great importance, but which hardly comes within the scope of

this work, may be briefly alluded to here. It is,—Should the tramways in any district be under the control of a Company or of the Local Authority? There is a good deal to be said on both sides.

It is, generally speaking, desirable that all undertakings which necessitate interference with streets and roads, and which affect the welfare of the inhabitants of a district, such as Tramways, and the supply of Water, Electricity, and Gas, should be in the hands of the Local Authority. The laying of a tramway line, under Parliamentary powers, carries with it the exclusive right of using vehicles with flanged wheels to run upon the rails, and, as a tram-car is bound to keep to the prescribed track, a monopoly of the streets is practically created. This monopoly ought not to be given for private profit.

The overcrowding problem, in so many of our large towns, can only be satisfactorily met by cheap and rapid means of transit to the suburbs, and the Local Authority would appear to be the right body to provide it.

While Corporations can generally borrow money at cheaper rates than Companies, the fact that they are bound to lay by a sinking fund, sufficient to redeem the whole of the capital in a stated period, often makes the annual capital charges from 5% to 6%. The practical result of this is, that a working profit of that amount has to be made annually, in order to prevent a call upon the rates.

With a Company the case is different. Its capital, being borrowed in perpetuity, is subject to no sinking fund charges, and any working profit is available for paying dividends. In the long run, the advantage is bound to be with the Local Authority, because the annual Sinking Fund payments are gradually extinguishing the

capital debt. But, for the moment, the Company can work more cheaply than the Local Authority.

Until recently, Municipalities were debarred from working tramways, although they might acquire or construct them, and thus we find many towns where the tramway undertakings are leased to Companies for certain periods. There is very little doubt, but that when the leases fall in, the Local Authorities will take over the working.

The tramways in this country, at the present time, are working under all sorts of conditions. In one town we find a Company running the system with conspicuous success, having previously bought it from the Local Authority, in whose hands it was a failure. In another town the Local Authority is working a system bought from a Company, which could not make it pay. In a third the tramways, laid down by the Local Authority, are leased to a Company. In a fourth town the Local Authority has laid down, and is successfully working, the tramways, while in a fifth town a Company has done the same thing.

Here, again, we find various arrangements. One Corporation sells current to a Company, another Corporation buys current from a Company, while a third Corporation obtains its electrical supply from its own works. But, in all cases, electric traction is proving itself to be the right thing for tramway working, and it is only a question of time for its universal adoption.

CHAPTER II.

GENERATING PLANT.

Definition—Direct-Current Generators—Rating—Sparking—Construction of Armature—Winding—Commutators—Brushes—Field System—Excitation—Shunt Machines—Compound Machines—Field Coils—Mounting Dynamos—Efficiencies of D. C. Machines—Alternating-Current Generators—Armature—Field System—Excitation—Steam Engines—Low *v.* High Speed—Vertical *v.* Horizontal—Compound *v.* Triple Expansion—Even-Turning Moment—Periodicity—Governing—Lubrication—Arrangement of Generator and Engine—Boilers—Mechanical Stoking—Steam Piping.

Definition.—The term "generating plant" practically covers the whole of the apparatus necessary for the generation of electricity in large quantities, and therefore includes not only the electric generators themselves, but also the steam engines and the boilers. Although, in modern practice, the dynamo and steam engine are practically one machine, it may be convenient to treat them separately.

Dynamos, or generators, may be broadly divided into two classes, according to whether they deliver a direct, or an alternating, current. The various conditions determining the use of either class, for electric traction purposes, are dealt with in Chap. IV. They are, briefly, the economical possibilities of transmitting the power generated to the points where it is to be used.

In this chapter no attempt will be made to deal with the theory of electric generators, but the matter will be

looked at more from the point of view of the user. We will first consider the direct-current generator.

Direct-Current Generators.—Until recently the only form in common use in this country was the two-pole machine, with a smooth core, drum-wound, armature. This type of machine, up to about 200 kilowatts output, and running at about 300 revolutions per minute, when coupled to a Willans and Robinson, Belliss, or other modern high-speed engine, makes a very neat and compact set, and its excellent performance has been a constant recommendation for duplication, when a more economical arrangement might have been with fewer machines of larger size.

For sizes above about 200 kilowatts, the two-pole machine becomes an impossible type, and recourse has to be made to multipolar generators. We may say, definitely, that the modern direct-current traction dynamo has now assumed the standard type of a multipolar machine with a slotted armature.

Machines of this type have been manufactured up to 3,000 kilowatts, at 600 volts, and 75 revolutions per minute. If the demand existed, there is no reason why even larger machines could not be made, although, owing to difficulty of distribution, it is very doubtful if direct-current generators would be used of larger size for electric traction purposes.

When dealing with machines of such magnitude as 3,000 kilowatts, the question of carriage is very important, and, for this reason, the entire armature has frequently to be built, and wound, "in situ," as the weights of a complete core, or armature, are beyond the capabilities of ordinary railway trucks.

Rating.—As machines increase in size, the diameter of

the armature core increases also, the following relation holding good—

$$KW. = \frac{d^2\ l\ k\ R}{1,000} \tag{7}$$

where $KW.$ = output in kilowatts.
d = diameter of armature in inches.
l = length of armature in inches.
k = a constant.
R = revolutions per minute.

The constant, "k," varies somewhat with the type and size of machine, from 0·02 for machines of 100 kilowatts, to 0·035 for machines up to 3,000 kilowatts output.

There is, however, some little latitude in the rating of the output, different makers having different temperature limits. It is safe to specify 70° Fahr. as the maximum temperature, above the surrounding air, to which any external part of the machine should rise, under continual full load. These requirements certainly limit the continual output of a machine, but the generator may often carry a considerably greater load than the normal for a short time, the only limits being the power of the engine to drive it, and the sparking at the dynamo brushes.

Sparking.—It is hardly necessary, at this date, to say that a generator, which has to satisfy traction conditions, must not only be sparkless up to full load without alteration of brush position, but should also be capable of giving at least 25% over-load for short periods, and without sparking, if the brushes be adjusted. Some makers, however, over-rate the output of their machines, by naming a current which cannot be taken with a fixed brush position without sparking, the lead of the brushes requiring to be varied with the current.

Such an output is really a fictitious one, and cannot

satisfactorily be obtained under working conditions. In comparing the merits of various machines, it is well to obtain the size of the core, as, by the formula given, a rough indication may be gained of the margin which the designer has allowed in the machine.

The great drawback to all direct-current generators is the commutator, and it is here that practically all the trouble originates. It is one of the most costly parts of the machine to construct, and it requires constant care to keep it in good running condition. Being made up of a large number of comparatively small pieces of copper, and insulation, it can only be held together by insulating material, of such unsatisfactory strength as mica, micanite, or presspahn, all of which substances are liable to change of shape when heated.

In consequence of this, commutators sometimes get out of truth, and then they have to be trued up, either by an emery wheel, or by a turning tool. This latter is a very troublesome operation, on account of the difficulty experienced in obtaining a correct turning speed.

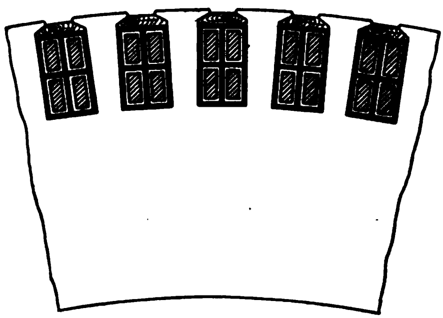
If only a satisfactory alternating-current motor could be obtained, there is little doubt but that direct-current machines would be discarded altogether, in tramway power houses, in favour of alternators, which are not troubled with commutators, and allow of a more economical distribution of energy.

Construction of Armature.—The construction of most direct-current generators is now very similar, and the following general description will apply to the principal makes.

On the driving shaft is mounted a massive cast-iron spider, which is the foundation of the armature, and on it the core and the commutator are built up. The core plates

are made of very thin soft sheet steel, which for small sizes are complete rings, but, when the diameter of the ring exceeds 4 ft., segmental plates are used instead. These are arranged so that the joints are broken in the adjacent layers. The core plates are slotted before they are mounted on the spider, and the spacing of the slots is usually so accurate, that, when the plates are assembled, a completely regular slot is obtained, right along the armature core, without much additional tooling.

Fig. 3.



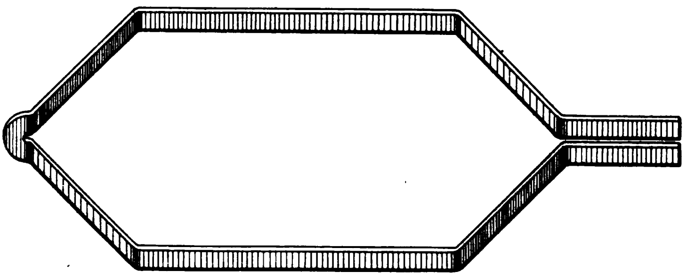
ARMATURE SLOTS, WITH CONDUCTORS AND WEDGES.

At each end of the armature core, ventilated cast-iron end plates are provided, on which the end connections of the armature windings are supported, if the armature be barrel wound. The core plates are separated, every three inches or so, by means of special distance pieces, in order to form a ventilating space about $\frac{3}{8}$ in. or $\frac{1}{2}$ in. wide.

Positive driving of the core is secured, either by means of keys let into both the spider and the core plates, or by internal projecting teeth on the plates, which fit into keyways or slots on the spider.

The slots, into which the armature conductors are placed, vary somewhat in shape in the different makes. From an electrical standpoint, a plain rectangular slot is best, and it is almost invariably used in small machines. In larger ones, where the problem of securing the conductors is one of some difficulty, the slots are often dove-tailed at the top, to allow of hard wood wedges being inserted over the winding, as shown in Fig. 3.

Fig. 4.



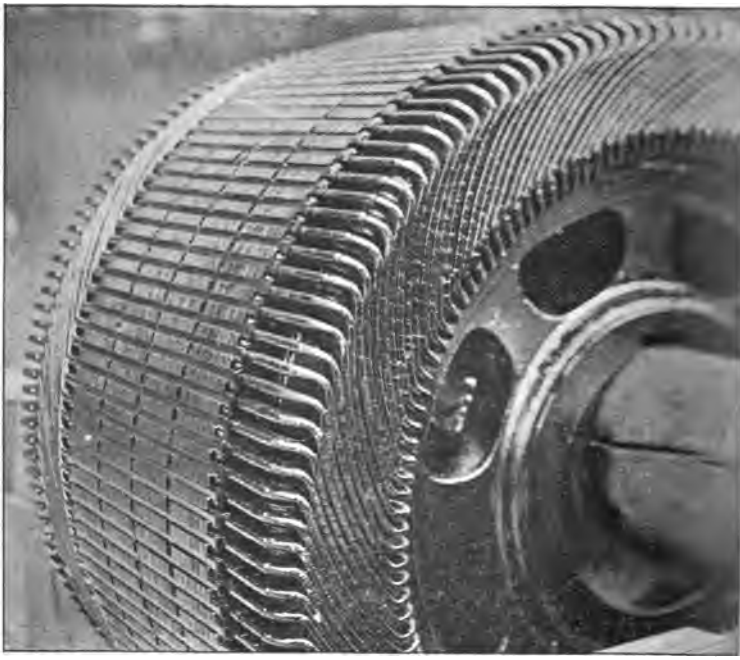
ARMATURE CONDUCTOR, BENT TO SHAPE.

As a rule, a wide, open slot is better than a narrow one, as giving less self-induction to the section under commutation.

Winding.—The conductors are made up of high-conductivity copper strip. The strips are bent, on their edge, round a $\frac{1}{4}$ in. or $\frac{3}{8}$ in. pin, until the two lengths are parallel, forming, when insulated, the top and bottom layers. They are then bent to the shape shown in Fig. 4, so that the two lengths lie in the correct core slots, forming the top layer in the one slot and the bottom layer in the other.

The conductors, being bent to their proper shape, are lightly insulated by means of strong calico tape. Those which are to go in one layer in one slot, are laid direct together and strongly insulated. The made-up conductors

Fig. 5.



ARMATURE, WITH COILS BENT OVER END PLATES.

are then steam dried, in order to drive off all moisture, and, while hot, are dipped into insulating varnish, or boiled linseed oil, until the insulating material is thoroughly saturated. The result is a strong, tough insulation,

practically impervious to moisture, and of considerable dielectric strength.

Some makers use no additional insulation in the slots, but rely entirely upon the insulation placed on the conductors. Others, on the contrary, line the slots with presspahn, or micanite troughs, and put less insulation on the conductors.

The barrel type of winding, as shown in Fig. 4, above, is perhaps the neatest and the easiest to repair, but it has the disadvantage that it takes up a considerable length beyond the core proper, the additional length being approximately the diameter of the armature, divided by the number of poles. In other types of windings, the ends of the coils are bent down over the end plates, as shown in Fig. 5, thus saving a considerable amount of space.

Commutators.—As was mentioned earlier, the commutator of a direct-current generator is perhaps the most vital part of the machine, and it requires the utmost care in manufacture.

It should always be made of hard drawn copper, the sectors being separated by not less than $\frac{1}{32}$ in. of mica, or micanite, of a quality which will wear equally with the copper. When the sectors and the insulation are assembled, they are held in very strong clamps, and the whole mass is gradually heated up, in order to drive off all moisture, and, during the process, the clamps are still further tightened up, until the whole is as solid and rigid as it can be made.

Double taper grooves are then turned in each end of the commutator, to take insulated clamping rings, which, when they are screwed up, hold the sectors together, against either inward or outward pressure. The whole

commutator is mounted, either upon an extension of the armature spider, or upon a separate sleeve firmly keyed to the driving shaft.

Modern commutators, with carbon brushes, wear very little, if they be properly looked after, but it is usual to provide a radial wearing depth of not less than 1¼ in. to 1½ in., for all large machines. The armature conductors are connected to the commutator sectors by means of lugs of copper strip, into which the conductors are soldered, the strips themselves being soldered, and riveted, into a saw cut in each sector.

One of the most troublesome faults in a commutator is the shifting of a sector, on account of the weakness of the insulating material, or of the end rings, the movement being caused by the expansion due to heating. There is no cure for this, except re-turning when the want of truth becomes serious.

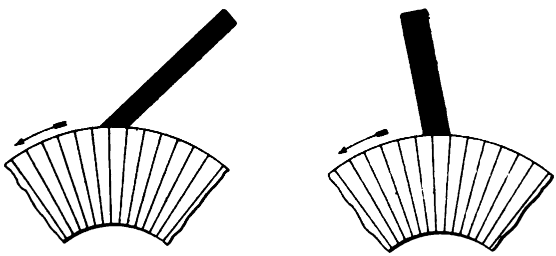
Another frequent fault is the breaking of the commutator connections. This can be avoided, to a great extent, by mounting the commutator in a thoroughly rigid manner on the shaft, or the spider.

Brushes.—Without collecting brushes the commutator would be useless, and there have been, perhaps, more types of brush-gear devised than of any other part of the machine. The perfect brush-holder has yet to be designed, but some of those found on modern machines are excellent. The requirements of a good brush-gear are (1) to hold the brush firmly against the commutator, by a light spring pressure, which will feed the brushes radially, and allow them to conform to any irregularity of the commutator surface, and (2) to ensure good contact between the brushes themselves and the brush-holder. The latter is usually accomplished by means of flexible connections, which,

while allowing perfect freedom of movement to the brushes themselves, yet form a good connection between the brush and the holder.

These apparently simple requirements are by no means easy of attainment, and, while modern brush-holders are a great advance on those in use only five years ago, yet there is still room for improvement. Brushes have been made of all kinds of material, firstly copper strip, then copper gauze, and now practically nothing but carbon blocks are used. For some time after the introduction of carbon brushes, they met with little favour, because they were

Fig. 6.



POSITIONS FOR COPPER AND CARBON BRUSHES.

tried in brush-holders which were only suited for metal brushes.

Carbon has a high specific resistance, and, being brittle, must be held in a special holder. Copper brushes are, in most cases, worked at a tangent to the commutator, or else at a moderate angle, but carbon brushes give the best result when they press radially on to the commutator. In fact, the tendency is to run the commutator against the brush, rather than with it. Fig. 6 shows the usual positions for copper and carbon brushes.

Among the reasons why carbon brushes are so success-

ful, is the fact that they do not cut the commutator like copper brushes, and because the high specific resistance much reduces the sparking, as the commutator sections are short-circuited when passing under the brush.

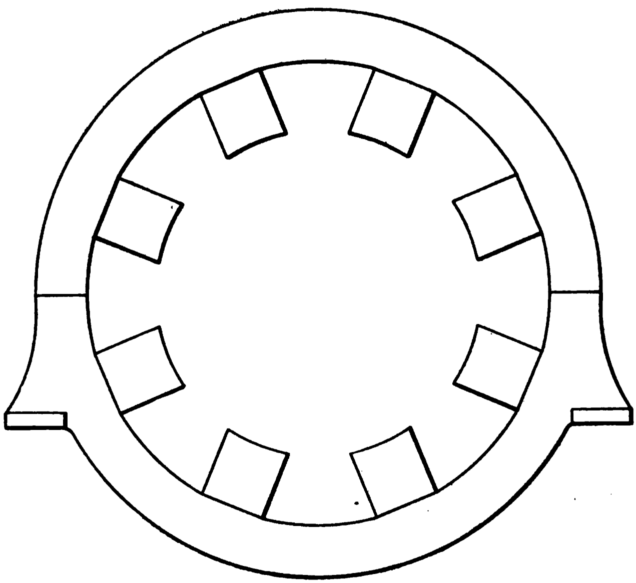
Field System.—In practically all modern direct-current generators the armature is revolved within a stationary field magnet system. In multipolar machines, such as we are considering, the magnets consist of a crown of poles, projecting internally from a common yoke ring, and the field coils are placed upon the poles. This type of field is an example of the survival of the fittest, as field systems have gone through many changes.

Some makers use cast steel throughout for both magnet poles and yoke rings, while others build up the poles of soft sheet steel, and cast the yoke rings round them. This latter type of construction is of service, particularly with large machines, as the armature slots cause variations of the magnetic flux, which would set up eddy currents in the pole faces were they not laminated. The lamination is sometimes obtained, with solid poles, by the use of special pole pieces, bolted to the inner faces of the poles.

Pole shoes, or polar extensions, are frequently used, both for the purpose of holding the field coils in place, and for obtaining a gradual tapering off of the magnetic field. The latter may be obtained without pole shoes, when the poles are built up of sheet steel, by cutting away the corners of every other plate so as to decrease the amount of metal at the tips. In Figs. 7 and 8 are shown field systems, with and without polar extensions, and although the magnetic distribution must be very different in the two types of machines, yet, with similar armatures, each type gives excellent results.

Excitation.—The field magnets of direct-current dynamos may be excited in several ways, but, for traction generators, which are required to give generally a constant pressure, under all conditions of load, there are only two methods to use, always assuming that the machines are self excited,

Fig. 7.



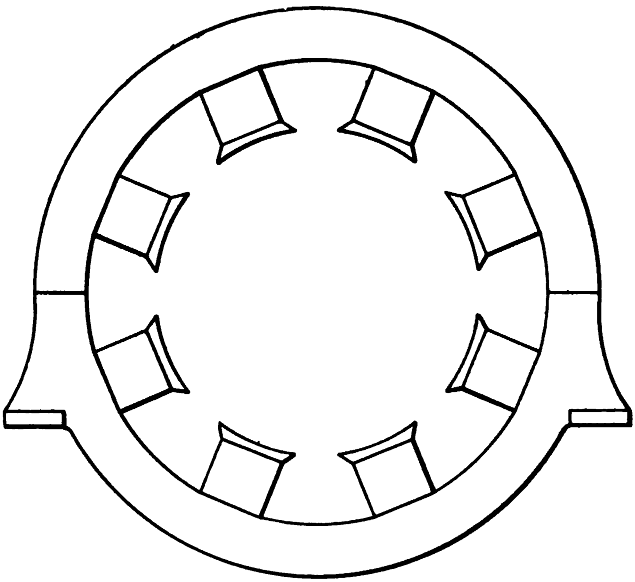
FIELD SYSTEM WITHOUT POLAR EXTENSIONS.

which is practically the universal custom. The two methods are (1) by shunt windings, and (2) by compound windings.

Shunt Machines.—The shunt-wound machine is shown diagrammatically in Fig. 9. The field coils are connected

directly to the terminals of the machine, and receive the full working pressure. With a constant pressure the magnetism would also be constant, independent of the load on the machine. But it is impossible to have a constant terminal pressure with a varying load, even if the field

Fig. 8.



FIELD SYSTEM WITH POLAR EXTENSIONS.

strength be constant, in consequence of the internal losses in the armature of the generator. In practice, the shunt-wound machine gives us a pressure which falls gradually as the load increases, and rises as the load diminishes. The exact amount of the variation will depend upon the

resistance of the armature, and upon the weakening of the field due to the armature current, but in any good machine it should not exceed 5 %.

In Fig. 10 is given what is called the "characteristic" curve of a shunt-wound dynamo. It shows the relation between the current output and the pressure at the terminals of the machine. It will be noticed that, as the

Fig. 9.

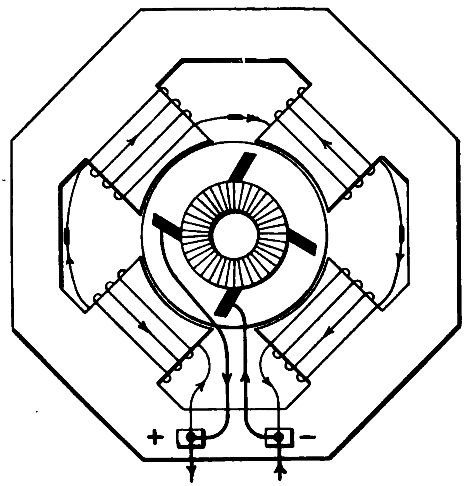
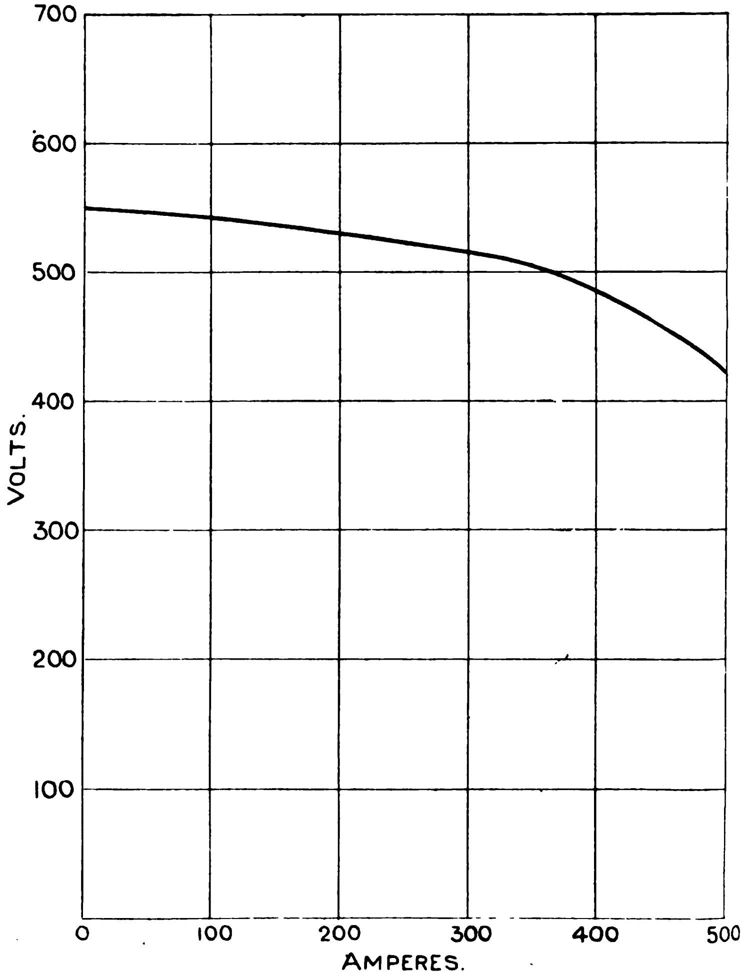


DIAGRAM OF SHUNT-WOUND DYNAMO.

current increases, the pressure gradually falls, the fall becoming more rapid towards the limit of the output.

The shunt-wound dynamo possesses several important features. It runs in the same direction, when driven as a dynamo, as it does when supplied with current from an outside source, and used as a motor. There is thus no danger of reversing the polarity when used in parallel with other dynamos, or when employed to charge accumu-

Fig. 10.



PRESSURE CURVE OF SHUNT-WOUND DYNAMO.

lators. For the latter purpose it is practically the only type of machine which can be satisfactorily used. Further particulars in this connection are given in Chap. XII.

Compound Machines.—When direct-current generators are used for tramway purposes, where the load often fluctuates rapidly between large limits, compound winding for the field magnets is most frequently employed. The

Fig. 11.

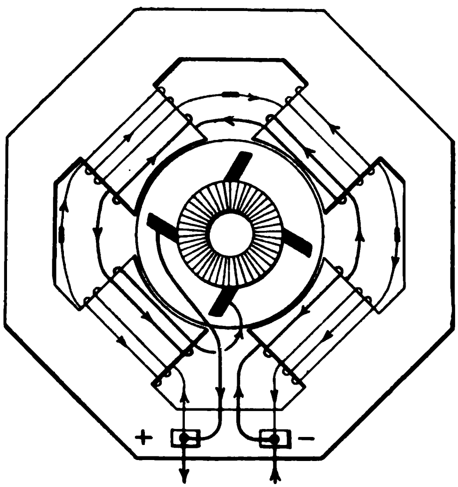


DIAGRAM OF COMPOUND WOUND DYNAMO.

compound winding is merely the addition of some series coils, through which the whole current of the machine is passed. This winding is shown diagrammatically in Fig. 11. The effect of the series coils is to increase the magnetism as the load increases, so that the pressure is kept constant, instead of falling off as it does with the shunt machine. As what is wanted is not really a constant pressure at the terminals of the dynamo, but rather a

constant pressure at the ends of the feeders, compound-wound machines are usually over-compounded, so that the pressure of the machine actually rises as the load increases. This over-compounding often amounts to about 10 %, *i.e.* the machine is made to give, say, 500 volts at no load, and 550 volts at full load.

Unless the magnets are worked some way under their saturation limit, it will not be possible to get over-compounding to this extent, without an excessive amount of series winding. As this would lower the efficiency of the machine somewhat, compound-wound machines have to be very carefully designed, particularly as working the magnets at too low a density results in instability of the field.

When a large number of feeders are employed, it is a question whether over-compounded machines are the correct ones to use, since the loads on the various feeders may vary considerably. The rise in pressure at the dynamo terminals will depend upon the combined loads, and thus the pressure at the far ends of individual feeders may be anything but constant. The best way would apparently be, to compound the machines for constant pressure only, and to use boosters (see Chap. IV.), on each feeder to raise the pressure as may be individually required by them. But, if boosters be used in this way, there is really no need to compound wind at all, and, considering the advantages which shunt machines possess, and particularly the growing tendency to use accumulators in connection with the generating plant, shunt-wound machines are, in the Author's opinion, the best in all cases.

When compound-wound machines are used in parallel, it is essential that not only should the terminals be coupled together, but also that the brushes should be connected as

well. This is done by a special equalizing switch, shown at S in Fig. 12. When bringing the second machine into action, the negative switch, N, of the incoming machine, and the equalizing switch, S, are closed. The positive switch, P, is closed when the voltage is correct.

Field Coils.—The field coils are generally wound on

Fig. 12.

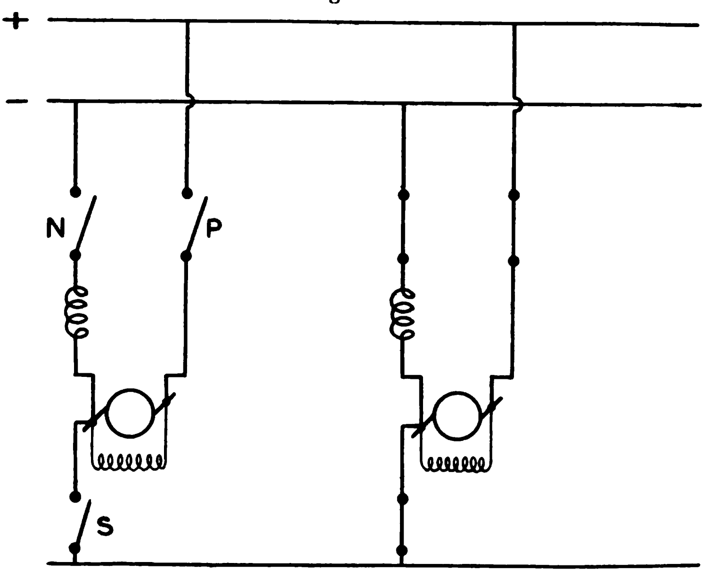


DIAGRAM OF TWO COMPOUND DYNAMOS IN PARALLEL.

metal formers, or frames, which are slipped over the magnet poles. When polar extensions are used, these are removed to get the coils into position, and then they are replaced, forming excellent supports. When there are no polar extensions, the coil frames have to be bolted to the magnets.

Trouble is often experienced in small dynamos through

the breaking of the ends of the shunt coils, and care is therefore necessary in handling them, unless they are provided with special heavy wires where the ends come out of the coils.

The series windings, having to carry the whole current of the machine, are often made of heavy copper strip forged into shape. The few turns are taped with insulating material, and treated in a similar way to the armature conductors.

When arranging the magnet coils on the poles of a multipolar dynamo during its erection, care must be taken that the coils are connected in their proper order, to give alternate N. and S. poles. If this be not done, it is very likely that some of the windings will oppose the others, and so prevent the machine from getting its proper output.

The magnet system of all multipolar generators is divided, either horizontally or vertically, into two halves, and, in very large machines, sometimes into four parts, both for ease of handling, and also to enable the armature to be put into place, or afterwards examined, without having to thread it through the magnets. Arrangements are often made for sliding the whole field system sideways, parallel with the shaft, to facilitate examination and repairs.

Mounting Dynamos.—In the case of small generating sets, it is usual to mount the dynamo upon an extension of the engine-bed. But, with large machines, this course is not practicable, since the base plate would require considerable spread to take the generator, and would also be too heavy to machine or handle. It is now the almost universal practice to mount the dynamo upon small independent base plates, and to rely upon the concrete foundations to preserve the relative positions of the engine and dynamo.

From what has been said of the difficulty of transporting and handling the heavy parts of large generators, it will be gathered that the erection of large sets is a lengthy process, and one which requires very great care, since, during erection, the surroundings are not often suitable for careful and rapid work.

Efficiencies of D. C. Machines.—The efficiencies of large direct-current generators are very high. The losses at full load are usually in about the following proportions, *i.e.*—

Armature copper losses ($C^2 R$), 2·2%.
Armature core losses (hysteresis and eddies), 2·2%.
Field copper losses ($C^2 R$), ·6%.
Commutator copper losses ($C^2 R$), and friction, 1%;
Full load losses, say 6%.

This makes an efficiency, of electrical output to mechanical input, of 94%.

Alternating-Current Generators.—Practically the only type of alternator, which is used in traction work, is that which gives three distinct alternating currents, differing in phase by 120°, and we will confine our attention to it.

At the present time * the largest example of such a generator in use in this country is at Glasgow, where there are four three-phase machines of 2,500 KW. each, in the Corporation Tramways Station. In America, however, eight machines of 5,000 KW. each, are being manufactured for the 74th Street Station of the Manhattan Elevated Railway, while machines of 3,500 KW. are quite common, both in America and on the Continent.

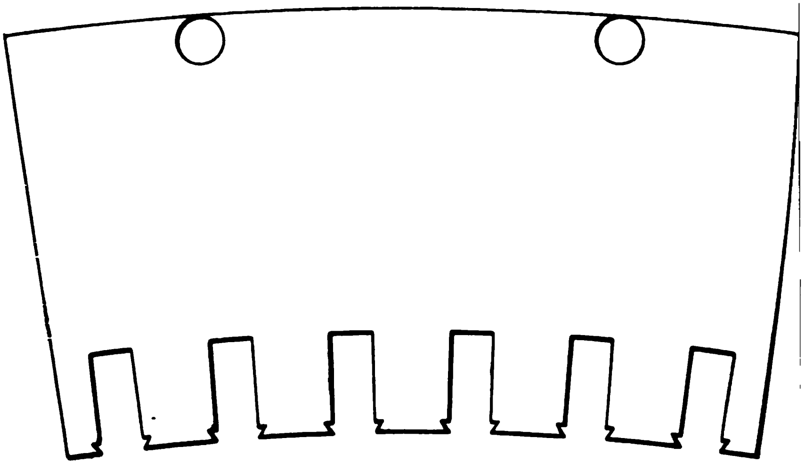
Although the design of alternators has not been stand-

* Since the above was written two machines each giving 3,500 KW. and generating *two-phase* currents, have been erected at the Willesden Works of the Metropolitan Electric Supply Co., Limited, London.

ardized so completely as that of direct-current generators, the following description will apply, generally, to the best examples of modern three-phase plant.

Contrary to the practice with direct-current machines, multiphase alternators usually have a stationary armature, and a revolving field-magnet system. This is advisable, because the use of multiphase machinery generally means

Fig. 13.



SECTION OF ALTERNATOR ARMATURE, SHOWING OPEN SLOTS.

high-pressure generation, and it is very advantageous to have no moving contacts on the armature, while the insulation of the high-pressure windings is much more likely to be permanent when the armature is stationary.

Armature.—The armature core consists of punched segments of very thin soft steel sheets. These segments embrace some two feet of the circumference, and the different layers are made to overlap each other, so as to

break joint. The built-up armature core is held together by a cast-iron box-shaped ring, having ventilating spaces between it on the outside of the discs. The internal circumference of the armature is provided with slots, similar in shape to those in the armatures of direct-current generators.

Fig. 14.

SECTION OF ARMATURE OF 3-PHASE GENERATOR.

These slots vary very much in size and shape in the various types of machines, but, for convenience of winding, the open slot, shown in Fig. 13, has many advantages. The armature coils can be shaped and insulated before leaving the manufacturer's works, and the soundness of each coil

tested before placing in the slots. The coils can be easily slipped into place, and then secured by hard wood strips, driven over the tops of the coils, and held in place by the side recesses, as shown in the figure.

The coils usually consist of a stranded copper cable, bent to shape, and treated in a similar manner to the coils of direct-current machines. The insulation, however, has to be carried out more carefully, since the working pressure is so much higher.

When closed armature slots are used, the winding is much more difficult, as each wire has to be threaded into place. As these large generators have generally to be built up in the power-station, such a method of winding is practically out of place, and is therefore not often adopted. In Fig. 14 is shown a section of the armature of a large three-phase generator, from which the shape of the various coils, and the way they are embedded in the armature ring, can be clearly seen.

Field System.—The magnetic system, revolving inside the armature, consists of a large fly-wheel, on the rim of which are fixed the projecting magnet poles. These are made of steel, and are often fitted with laminated pole shoes, to prevent eddy currents. The pole shoes also take an important part in holding the field coils in position.

The field coils, having to stand a high centrifugal strain, are usually made of copper strip, wound on edge in one layer. This necessitates the voltage of the exciting current being kept low, and manufacturers prefer that it should not be over 100 to 120 volts. Fig. 15 shows a portion of a field-magnet system such as would be used for the three-phase armature illustrated in Fig. 14.

Excitation.—The armature, being stationary, has its windings connected directly to the switchboard, without

moving contacts of any kind. A direct current, however, has to be used for the field coils, and two plain collecting rings are mounted on the shaft, and connected to the two ends of the field coils. By means of ordinary carbon or copper brushes, current from an independent exciter is taken.

As a direct current is necessary for exciting all alternators, it is not possible to make them self exciting, unless a

Fig. 15.

PORTION OF FIELD SYSTEM FOR 3-PHASE GENERATOR.

special rectifying apparatus be used. This is seldom done, the most satisfactory method being to employ a separate direct-current machine mounted upon, or driven from, the alternator shaft, or connected to its own driving engine.

In large power-stations it is usual to employ separately-driven exciters, but this has the disadvantage of a number of comparatively small engines and pipe connections. Each exciter is large enough to excite a number of alter-

nators, and special field switches have to be provided, to make and break the various field circuits as required.

The practice of using an independent exciter for each alternator, driven from its shaft, has much to recommend it. The field current starts and stops with the starting and stopping of the alternator, and therefore the field circuit is never broken. The regulation can also be done by varying the field of the exciter. The failure, however, of this small exciter would put a large alternator out of action, and a standby of some kind or another has to be provided. This may take the form either of a battery of accumulators, a separate steam-driven exciter, or a motor generator driven from the three-phase plant.

The efficiency of a large alternating-current generator is very high, often reaching 95%.

Steam Engines.—Excepting where water-power is available, steam engines form the only motive power for large generators. Practically every type of steam engine is in use, from the large low-speed horizontal engine, running at 75 revolutions per minute, to the steam turbine, with its 1,500 revolutions and over. Each type of engine has its own advocates, some basing their preference on efficiency in steam consumption, others on reliability in running and freedom from repairs. Like many other things, the best type of engine is really a compromise between a number of diverse factors.

Low *v.* High Speed.—Low speed of rotation means a large and costly plant, both in the machine itself and in the foundation and buildings necessary. When the preference of many engine builders for low-speed engines is analysed, it will be found that the real reason for the low speed is the valve gear employed. Corliss gear, with its trip motion, has been a favourite for many years, on

account of the high economy obtained in mill engines, where the load is more or less uniform throughout the day. It is difficult for those, who have been accustomed only to low-speed Corliss engines, to realize that there can be any merit whatever in higher speed engines, with a different valve gear. But the whole of the circumstances must be taken into account, when deciding upon the right type of engine.

In mill work, the engine alone has to be considered, since the correct speeds for the various line shafts can always be obtained by a proper proportioning of the rope-driving pulleys. But, in driving direct-coupled electrical machines, the generators have as much right to be considered as the engines, and, from their standpoint, a high speed is most desirable. High speed means, for them, small comparative size, high efficiency, and small cost. If it had not been for the limiting speed of Corliss gear, which does not work satisfactorily over 100 revolutions per minute, and for the influence of marine practice, where the speed of the engine is limited to that of the propeller it has to drive, there is little doubt that high-speed engines would have been in universal use in power-stations.

As it is, the high-speed enclosed engine practically holds the field for small units, say up to 500 H.P., but there are at present very few generators of 1,000 KW. or over, which are driven by anything other than low-speed engines.

Vertical *v.* Horizontal.—The comparative merits of vertical and horizontal engines have not caused such variations of opinion as the speeds. Even low-speed engine-makers admit that vertical engines are the best for electrical driving, since they take up far less ground space, have much less wear in the cylinders, and are, in other ways, better suited for the purpose. But

the adoption of the vertical type does away with one of the chief merits of the Corliss valve, which is its excellent draining facilities, when used on a horizontal cylinder.

Compound *v.* Triple-expansion.—Whether the engines should be compound or triple-expansion will depend upon the steam pressure available. In all modern plants the tendency is to increase the steam pressure, and up to 200 lbs. per square inch is becoming common. Such high pressures naturally call for triple-expansion engines, but it is questionable whether the added complication of a third cylinder, with its crank and valve gear, is warranted, in view of the comparatively small increase in efficiency due to the use of three expansions, rather than two. Compound engines, for such a varying load as that of a tramway system, will give an all-round efficiency practically equal to that of a triple-expansion engine, and, in the Author's opinion, a steam pressure of 160 lbs. per square inch, with compound engines, is the best working arrangement.

Even-turning Moment.—One of the most important points to consider, particularly in engines which have to drive alternators, is that of obtaining a perfectly even speed of rotation. This is an entirely different thing to good governing. Good governing simply means that the speed of the engine shall be kept within small limits, whatever the value of the load. Even speed of rotation, or even-turning moment, as it is called, means that the angular velocity of the fly-wheel, or the rotating part, must not vary during any revolution. It should be possible to keep the variation under 0·2 per cent. This is a far more difficult thing to obtain than good governing, since the impulses given to the shaft occur, in double-acting engines, twice per revolution per cylinder. This again

depends upon whether the cranks are placed opposite each other or not.

When two cylinders are used, the practice is to place the cranks at right angles to each other, thus giving four impulses per revolution. In some types of small engines the two cranks are placed opposite each other, and are thus equivalent to only one crank, so far as the turning moment is concerned. When three cranks are used, they are always placed 120° in advance of each other, so as to give six impulses per revolution. The variations of velocity, which occur between the impulses, are levelled out by means of the fly-wheel, the fewer the impulses the heavier being the fly-wheel required to maintain constant angular velocity.

A type of engine, recently introduced in the power-station of the Manhattan Elevated Railway, New York, has four cylinders, a high-pressure horizontal, and a low-pressure vertical, on each side of the generator. The two cylinders on each side work on a common crank, and the two cranks are set at an angle of 135° apart. Fig. 16 shows the arrangement diagrammatically, and it will be seen that eight impulses per revolution are obtained, with the result that no fly-wheel, other than that of the revolving field system of the alternator, is needed.

Periodicity.—Even angular velocity is absolutely essential when alternators are run in parallel, since any angular variation tends to throw the machines out of synchronism. The actual amount of angular variation which can be allowed depends upon the periodicity, or number of complete alternations per second. The lower the periodicity, the wider is the angle covered by any armature coil, and the greater is the permissible variation in the angular velocity. It will be evident, that high-speed engines will

give a much better turning moment than low-speed engines, since the number of steam impulses per second must be considerably greater.

Fig. 16.

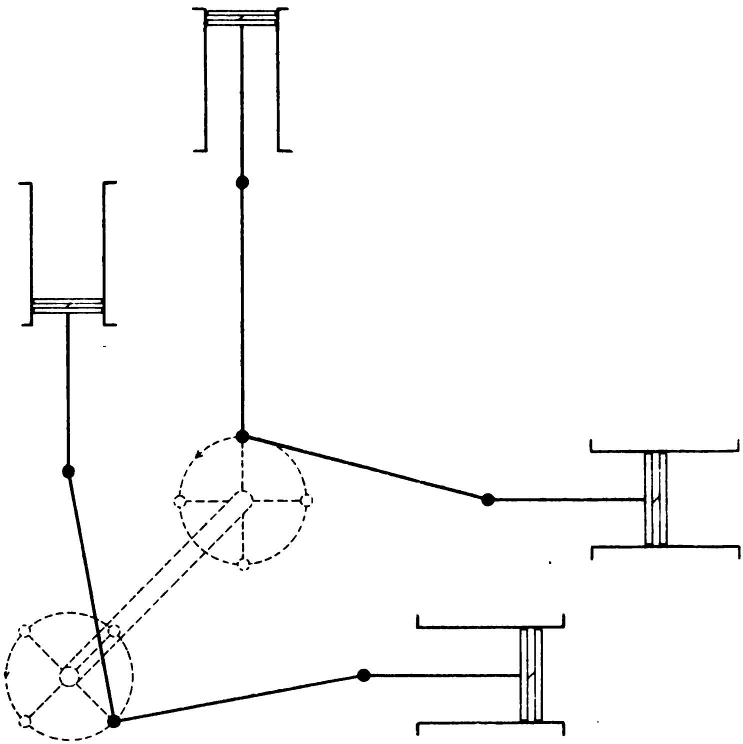


DIAGRAM OF 4-CYLINDER 2-CRANK ENGINE.

Periodicities as high as 100 ~ per second were quite common in this country some years ago, with single-phase alternators used for lighting purposes. But, since power-work, with 3-phase alternating currents, has become pos-

sible, the value of low periodicities has been recognized, and, for such work, 25 to 40 ∼ per second is now the usual practice.

Governing.—It was mentioned above, that good governing was not essential for good parallel running, and many of the difficulties which have been experienced in the past, in running alternators in parallel, would have been avoided, had more attention been given to even-turning moment and lower periodicity, and less to good governing. In fact, alternators run best in parallel, when their steam engines have no governors at all. This is quite a common experience, and yet, to-day, we find engineers specifying such close governing as from 2% to 3% maximum variation, between no load and full load.

Fine governing generally means unstable governing, and it is not essential that the speed of the generators should be kept so absolutely constant during their run. The regulation of the pressure should be done at the switchboard, and much better working results would be obtained, if engineers would decline to accept governors which control the engine speed closer than 5%. Between 5% and 7½% is an excellent working figure, and will be found to give the best all-round results in practice.

The governors of all engines for driving generators should be so arranged, that they can be adjusted while the engine is running, since the loads on the various machines are best controlled by altering the steam admission. The voltage of the generators should be governed by altering the excitation of the field, and the division of their loads by the steam.

Lubrication.—One of the most important points in the satisfactory running of any steam plant is that of lubrication. For many years nothing but the old-fashioned sight-

feed, drop-by-drop, lubricator was to be obtained. It was most uncertain in its action, and required constant refilling from an oil-can. But the best modern practice is to use forced lubrication throughout. The result is not only an enormous economy in the use of the oil, but hot bearings are now almost unknown.

A large cast-iron tank is formed in, or under, the bed of the engine, and, by means of small force-pumps, worked direct from the engine, the oil is pumped up and through a system of feed pipes to all the working parts of the engine. The pumping is done at a pressure of from 15 lbs. to 30 lbs. per square inch, and all the working parts are thus copiously served with oil, the engine practically running in a bath of oil. The used oil drains back into the tank, where it passes through filters and whence it is pumped for use again.

Forced lubrication, in this manner, necessitates a closed-in engine. Those engineers who are accustomed to having the whole of the working parts under their eye, always look with suspicion upon an engine which is boxed in. But boxing it in makes forced lubrication possible, and, at one stroke, does away with the mess of an open engine, the continual attention with the oil-can to the various lubricators, and, to a very large extent, with the numerous small adjustments necessary. Forced lubrication is the secret of successful high-speed engine running.

Many engine-builders, when adopting forced lubrication, attempt to apply it to an engine of the ordinary open type, closing in the various parts by means of sheet steel lagging, and other devices. Such arrangements should never be accepted, as they only indicate a patched-up job. If forced lubrication be adopted, the engine should be designed from start to finish in accordance therewith.

Arrangement of Generator and Engine.—A matter upon which there is a great diversity of opinion, is whether the generator should be placed outside the engine, or between the engine divided. In the former case the generator is more easily got at, but there are, at least, four main shaft bearings to keep in line, and the power of the outside cylinder has to be transmitted to the generator, through a twisted shaft, *i. e.* one with a crank in it. In the latter case there are only two bearings on the main shaft, the power is transmitted directly to the generator, and the whole arrangement is much superior. For very large units the four-cylinder, two-crank, type of engine mentioned above, with the generator in the centre, would appear to be, from almost every point of view, the ideal one to adopt.

Boilers.—Of equal importance with the steam-using plant, is the steam-raising plant. Boilers in modern traction generating-stations are now practically confined to two types, viz. the Lancashire boiler, and the water-tube boiler. Boilers of the marine and locomotive types are seldom met with, excepting in older stations. Each of the two former has its advantages and its advocates, but where ground space is not a serious factor, the Lancashire boiler is certainly the better. There is no necessity, in this book, to describe in detail the characteristics of these two types, as they are well known, but a few remarks on their working may not be out of place.

The Lancashire boiler, with its long cylindrical shell, is not so suited for such high pressure as 200 lbs. per square inch as is the water-tube boiler. It is often made for such a pressure, but the shell, and the end plates, have to be exceedingly thick, from $\frac{3}{4}$ in. to $\frac{7}{8}$ in. metal being used. Not only does this make the boiler exceedingly heavy, and

difficult of transport, the weight of a single boiler often amounting to twenty-five tons, but the foundations have to be much stronger, and the water in the boiler is separated from the fire by much thicker metal. The water-tube boiler, on the other hand, occupies less ground space, is made in comparatively small pieces, and can be handled and erected much more readily.

One of the advantages, formerly claimed for the water-tube boiler, was its freedom from explosion. Certainly an explosion in a water-tube boiler is not likely to be so dangerous as one in a Lancashire boiler, since the volume of water and steam in the former are so much smaller. But the water-tube boiler is far more subject to damage than the Lancashire boiler. If forced very hard, over-heating of the tubes is liable to take place, and it is nothing unusual, in a large power-station, to see a water-tube boiler out of use, for the time being, while new tubes are being fitted. With the furnace arrangement usually adopted, it is practically impossible to work a water-tube boiler smokelessly, at any rate with bitumenous coal, on account of the sudden cooling of the gases, as they strike the first row of water tubes.

The Lancashire boiler is slightly more efficient, as a steam raiser, than the water-tube boiler, and, since it carries a larger supply of water, and has a larger steam space, it is not nearly so liable to fluctuations in the steam pressure as is the water-tube boiler. These very advantages, however, make steam raising a much longer process in the Lancashire than in the water-tube boiler. In traction stations, where the load, although fluctuating very much, yet maintains a fair average value, the Lancashire boiler is perhaps the best that can be used. For lighting stations, which are liable to very sudden

demands on account of local fogs or other reasons, the water-tube boiler has many advantages. In a large number of generating stations, boilers of both types are in use, the water-tube boilers being relied upon for emergencies, and the Lancashire boiler for the steady load.

In London, and other places where ground space is of enormous value, there is practically nothing else to do but to use a boiler of the water-tube type, since head room can be more cheaply obtained than ground area.

Lancashire boilers are made by a large number of firms, and the leading dimensions have been thoroughly standardized. Water-tube boilers, however, are made in several forms. One of the best known has a number of inclined tubes, joined together at the back and front by common headers, connected to a steam drum over. Another has two water-drums below and three steam-drums above, connected by a large number of almost vertical pipes. The advantage claimed for this type, is that the soot does not collect on the exterior, nor water scale on the interior, to anything like the same extent as on the inclined tubes in the other type. In each case, steam jets, with a flexible hose, are used to blow the soot from the outside of the tubes at intervals during working.

Mechanical Stoking.—Mechanical stoking is an absolute necessity in any large station. Where there are only two or three boilers in use, no saving in labour will be made, since one man must be kept in any case, while the capital and repair charges on the stoking plant would practically make up for any saving in fuel. But, for large power-houses, a considerable economy is obtained. Not only can one stoker attend to a number of boilers, but a saving in fuel can be guaranteed, on account of the more perfect combustion.

It is well known that first-class hand firing is better than any mechanical stoker, but such a thing is exceedingly hard to get. The average stoker can shovel on coal, but he often has a very poor idea of the correct way in which it should be done, with the result that hand firing, as usually carried out, is not so efficient as a good mechanical stoker.

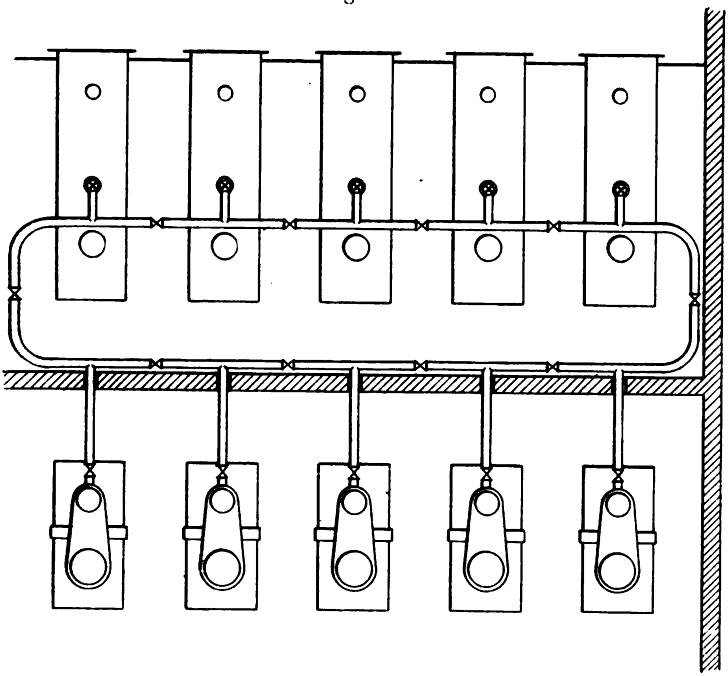
Mechanical stokers are of two distinct types, viz. coking stokers and sprinkling stokers. In the former, the coal is pushed on to a dead-plate immediately in front of the fire, where it is coked, the gases given off passing over the live fire in front, and so becoming consumed and preventing all smoke. The coal is gradually pushed forward by means of moving fire-bars, until it is carried right over the grate, and falls into the ash-pit at the end. This type of stoker gives excellent results, from the points of view of good combustion and prevention of smoke, but, in order to get the full duty out of the boiler, it has to be worked at such a rate as to make it extremely likely that unconsumed coal will be carried over into the ash-pit. It is also rather expensive to keep in repair.

The sprinkling stoker, as its name implies, is one in which the coal is scattered, or sprinkled, all over the fire by means of an automatic shovel, or sprinkler. This type of stoker, while enabling full duty to be obtained from the boiler, is very likely to cause smoke, if worked at anything like its full rate. There are various modifications of these two main types of stokers on the market, but space will not permit of any mention of them.

Steam Piping.—Of equal importance with the boilers, and the steam engines, are the pipes connecting them, forming, as they do, a necessary link in the chain. Steam-pipes are now always made of lap-welded steel, with

flanges screwed on. In order to ensure continuity of steam supply, the pipe system should have very great care expended on its design and erection. There are several pipe systems in use, each endeavouring to obtain freedom from breakdown, and many of them involving disadvantages almost as serious.

Fig. 17.



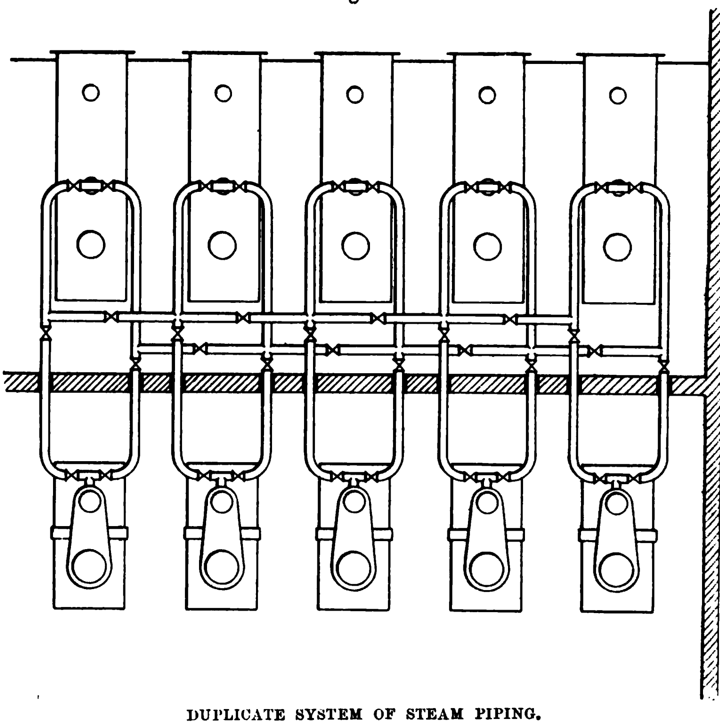
RING SYSTEM OF STEAM PIPING.

One of the earliest systems was to use a complete ring of piping, either in the boiler-house, the engine-house, or both, into which each boiler and each engine was connected. By means of valves, suitably placed, any

engine or boiler could be shut off, without affecting the rest, and steam could always be supplied to any engine, from either part of the ring. Fig. 17 shows a diagram of this method.

While this system certainly had the advantage of a

Fig. 18.

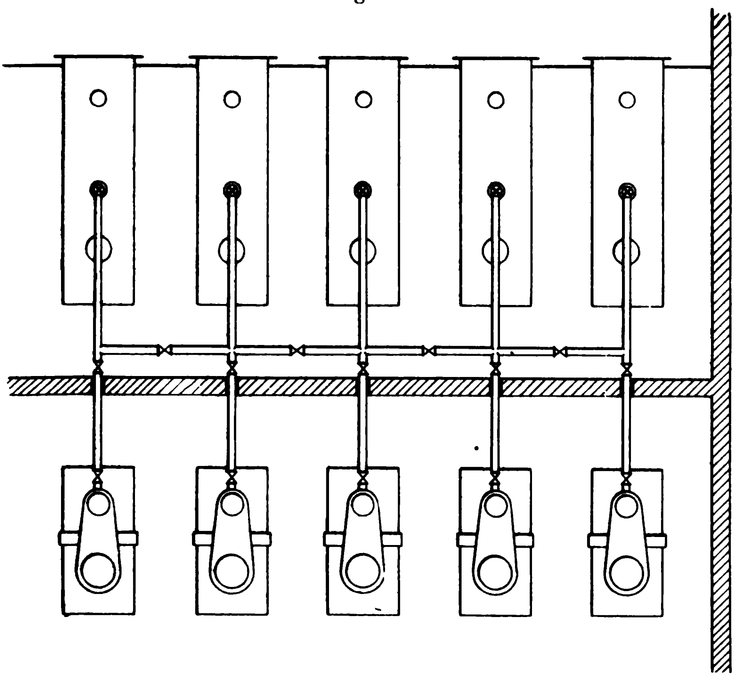


DUPLICATE SYSTEM OF STEAM PIPING.

duplicate path for the supply, yet the very great length of main piping which it involved, has proved to be a serious disadvantage. The great condensation, which resulted, has been more than sufficient to condemn it.

Another method for obtaining a duplicate path to each engine, was to employ two sets of steam piping throughout, the connecting pipes between engines and boilers being cross connected by a common header. This has proved nearly as wasteful as the ring system, since, if both

Fig. 19.



DIRECT SYSTEM OF STEAM PIPING.

sets of pipes be kept alive, when only one is required for use, heavy condensation must go on, and, if only one set of pipes be in use, the other set requires warming up before it can be used, and hence is of small service in case of

sudden emergency. Fig. 18 shows a diagram of this method.

By far the simplest, cheapest, and most reliable system is to reduce the length of piping to the smallest possible amount, to use nothing but the very best material, and to arrange the pipes as shown in Fig. 19.

Each boiler is connected to the main header, and from the header a supply pipe goes direct to each engine. It will depend upon the relative sizes of the boilers and the engines, how much steam will ever have to pass along the header itself, but in no case will it be more than that taken by any individual engine. Any failure of the pipes can only result in one unit being thrown out of use, and the risk of even this happening is so small, that it will not pay to complicate the pipe system by any duplication. The arrangement, shown in Fig. 19, can of course be modified in several different ways, but, in principle, it is far and away the best system of steam piping to adopt.

The details of coal storage, coal and ash conveying, feed pumps, condensers, steam traps, etc., are all most important, and upon their proper design and carrying out will depend to a very large extent the economical and satisfactory performance of a generating plant. Space, however, prevents them being dealt with here.

CHAPTER III.

SWITCH GEAR.

Importance of Switch Gear—Requirements of Switch Gear—Fundamental Points—Flat Panel Type—Ferranti Type—Protected Type—Keyboard Type—H. T. Fuses—H. T. Circuit Breakers—H. T. Switches—H. T. Ammeters—H. T. Voltmeters—Synchronizers—Divided Bus Bars—L. T. Switch Gear—L. T. Circuit Breakers—L. T. Switches—L. T. Ammeters—L. T. Voltmeters—Field Resistances—Field Switches—Board of Trade Tests—Position of Switch Gear.

Importance of Switch Gear.—The switch gear in a modern traction station is, perhaps, the most important of all the apparatus, consisting, as it does, of a compact collection of switches, circuit breakers, and measuring instruments, through which the whole output of the station has to pass.

It is possible to have duplication of every other part of the system, but, from the nature of the situation, this cannot be done with the switch gear, and its relative importance is therefore greatly increased.

In the early days, anything was thought sufficient to control the machines and circuits. Switches and instruments were mounted upon wooden panels, cables were bunched indiscriminately at the back, and the whole arrangement was generally ready to burn down at the first opportunity.

Experience in the requirements of the case, and in

methods of manufacture, has resulted in elevating the design and construction of switch gear to its proper place, and, although faulty arrangements are still to be met with, an up-to-date switch gear is now quite easy to obtain.

Requirements of Switch Gear.—The requirements of a modern switch gear are, briefly stated, as follows, viz.:—

(1) To enable generators and circuits to be rapidly and efficiently connected to and disconnected from each other.

(2) To disconnect faulty machines or circuits automatically, without affecting those remaining in use.

(3) To furnish correct indications of the working pressure, and the current output, of any of the machines or circuits.

(4) In the case of alternating current plant, to provide a ready means of indicating when the different generators are in synchronism with the other.

(5) To provide a means whereby the pressure of any, or all, of the generators can be regulated, or adjusted, as may be desired.

These various requirements are more or less satisfactorily met, in several designs of modern switch gear, although the types vary largely in their details. While intended to perform similar functions, the switch gear for high-tension traction plant is necessarily different from that for low-tension plant, because of the different problems encountered when handling currents of high pressure, and because, in practically all cases, the use of high-tension means the employment of alternating currents. In this chapter we will first consider high-tension alternating current switch gear, and then gear for low-tension direct current work.

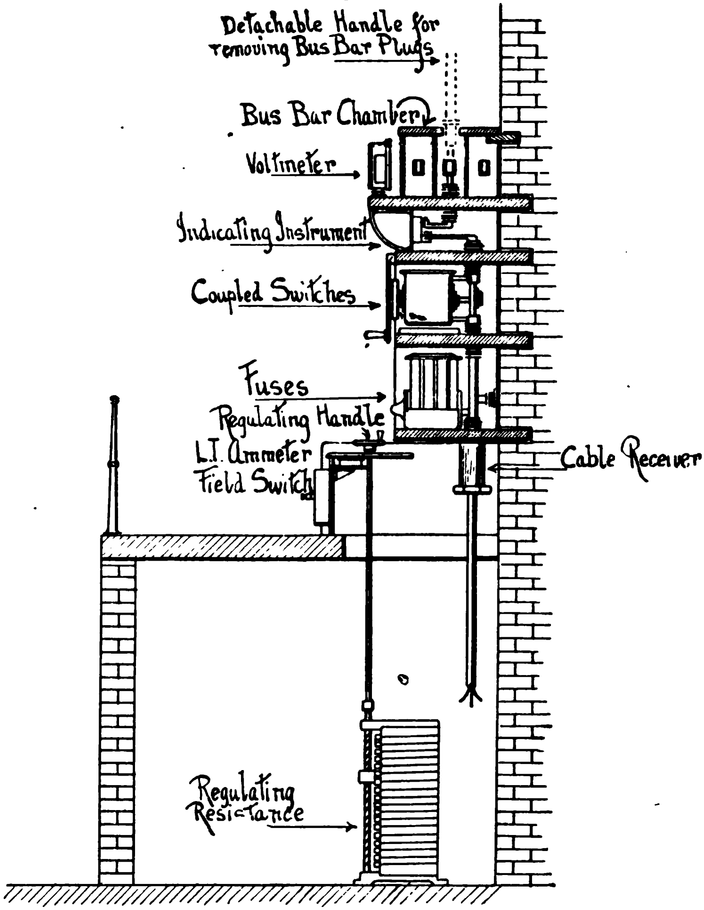
Fundamental Points.—In all switch gear design, certain fundamental points should be kept in mind. The apparatus, belonging to any generator or circuit, should be arranged in a vertical line, so that its relation may be seen at a glance. Switches, and such like, which have to be worked by hand, should be set in a horizontal row, at a convenient hand height. Circuit breakers of the magnetic type, which can be reset by hand, should be placed at the top of the panels, high enough to prevent any arcing from inconveniencing the attendant, but not so high as to take them out of reach. If fuses be used, instead of circuit breakers, they should be set below the switches. The aim, in arranging the various apparatus, should be to make each panel its own diagram.

Flat Panel Type.—Until recent years, the practice was to use flat panels of slate or marble, and to mount upon them the various apparatus. Connections from the various machines, and the circuits, to the switch gear, and between the various parts of the switch gear, were made, behind the panels, by means of insulated cables, connecting the metal shanks projecting from the apparatus. Such a switch gear always required a space behind it, to allow of the access of workmen, for the purpose of cleaning, examination, or repairs. This involved little or no risk to life, in the case of low-tension switch gear, but, when dealing with pressures of over a few hundred volts, there was very great danger of accident. Not only so, but the bringing up, into a small space, of a large number of wires, insulated with more or less inflammable material, made the whole arrangement extremely undesirable.

Ferranti Type.—About 1894 a type of switch gear, for single-phase high-tension alternating currents, was introduced by Mr. Ferranti, which, at one stroke, practically did

away with the whole of the disadvantages just named,

Fig. 20.



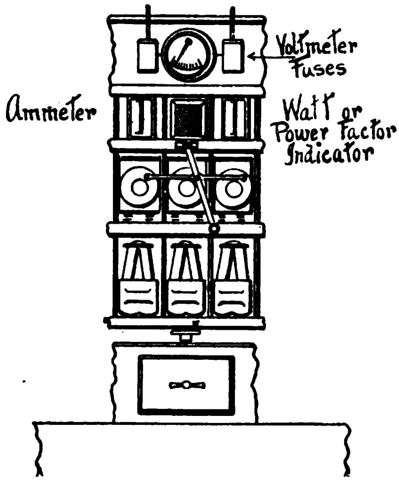
SIDE VIEW FERRANTI HIGH-TENSION SWITCH GEAR.

there being no open back, and no internal cable connections. The principle of the arrangement, which has

now become almost standard in this country, is as follows.

Instead of using flat slate panels, with the apparatus mounted in the front, the switch gear is placed upon horizontal slate shelves, built into the wall of the room. Vertical division slates are fitted between the shelves, forming a number of deep recesses, containing the appara-

Fig. 21.



FRONT VIEW FERRANTI HIGH-TENSION SWITCH GEAR.

tus. It was not possible to use switches, fuses, or instruments of the ordinary type, and, in consequence, special ones were designed for the purpose. In Figs. 20 and 21 are given a side and front view of the Ferranti switch gear, and from them the general arrangement will be understood.

It will be seen that the various apparatus make their own connection in a vertical line, the one with the other, so that all cable junctions are avoided. There being no back space, it is impossible for any accident to happen

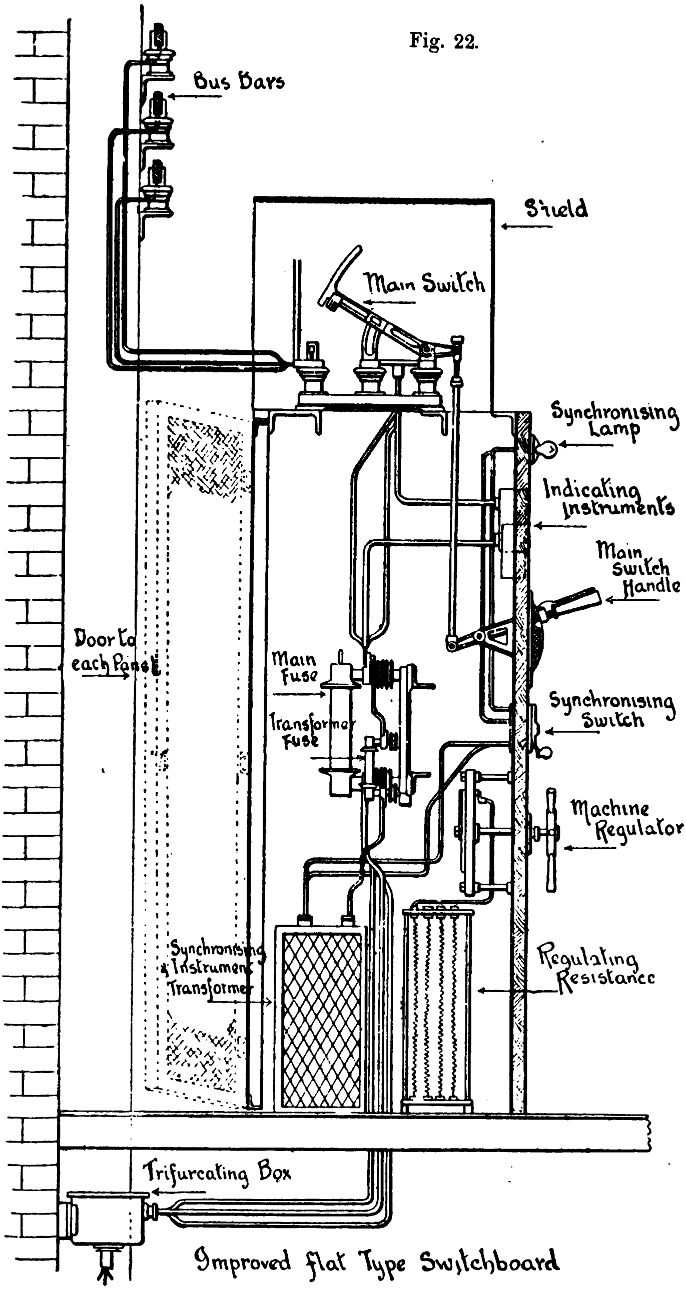
behind the switch gear, and it is not possible to touch any of the live metal, without putting one's hand deliberately into the deep recesses. The fuses and the measuring instruments make contact by means of spring jaws, so that any of them may be removed from place for examination, by merely pulling them forward.

Protected Type.—When dealing with very high-tension currents, such as 5,000 volts and over, extra precautions have to be taken, to prevent any chance of injury to the operator. A type of switch gear, in which all parts carrying a high-pressure current are placed at the back of the panels, is sometimes used. The various switches are worked by means of levers, passing through openings in the panels, so that the operator is entirely protected. The space at the back of the gear, however, with all its dangers, still remains. Fig. 22 illustrates a panel of this type.

Keyboard Type.—Another type of switch gear, which may be called the "keyboard" type, is in use in New York, at the generating stations of the Metropolitan Street Railway Company, and the Manhattan Elevated Railway Company. The switches are placed in isolated brick chambers, on an elevated gallery, and are controlled from a keyboard in a convenient position, through the medium of compressed air in the former, and small electric motors in the latter case, which operate them. This type of switch gear appears to be not only very complicated, with its large number of small control wires, but also very costly. It is, however, doing good service in the cases mentioned, and, no doubt, will have an extended use in the future.*

* For some exceedingly valuable information on high-tension switch gear, the reader is referred to an admirable paper by Mr. W. H. Clothier, read before the Manchester section of the Inst. Elec. Eng. in Feb. 1902.

Fig. 22.



Improved Flat Type Switchboard

PANEL OF PROTECTED SWITCH GEAR.

H. T. Fuses.—We will now consider, briefly, the various apparatus which, when assembled, constitute what we term switch gear. Both fuses and circuit breakers are used for the purpose of automatically opening the circuit when an excess of current passes. The former consists of a length of fusible metal, generally a wire, through which the whole current of the particular generator or circuit has to pass. The size of the wire is selected, so that, while the normal current only raises the temperature to a moderate degree, an excess current, of from 50% to 100%, will melt the wire, and so break the circuit. For high-tension work, a fuse is a very awkward thing to handle, and many devices have been tried, to render its operation both certain and also free from danger.

The early types consisted of a long length of copper wire threaded through a tube of porcelain, or similar material, and clamped by screws, at each end, to the terminals. The use of the tube was both to protect the wire, and also to create a kind of chimney draught, when the fuse melted, which assisted in putting out the arc. These fuses were often several feet in length for high pressures, and were not only exceedingly awkward to replace, but were also likely to maintain the arc, if the fuse were blown under a heavy short circuit.

One of the best types of fuse is that employed in the Ferranti switch gear mentioned above. In Fig. 23 is shown such a fuse, from which it will be seen that a porcelain box is used, having a central division piece. The terminals of the fuse pass right through the porcelain at the back, and are connected to two strong springs, which normally lie at the bottom of the box. The fusible wire is connected from the end of one spring to the other, thus bridging across the central partition. When inserting the

fusible wire, the springs are brought close up to the top of the box, so that the actual length of wire is very short, and the springs are thus kept in tension. The whole box is then filled with heavy resin oil, the only part left exposed being the small pieces of fuse wire across the

Fig. 23.

FERRANTI OIL FUSE.

partition. Should an excess current pass, and melt the wire, the springs immediately pull the ends right to the bottom of the box, beneath the oil, thus completely extinguishing the arc. Such fuses have proved remarkably successful in practice, on pressures up to at least 5,000 volts, and with large currents.

An interesting type of fuse, in which the arc is extinguished by a jet of carbonic acid gas, at high pressure, has recently been invented by Mr. G. W. Partridge. A "sparklet," such as is in common use for aërating liquids, is employed, and, on the steel cylinder becoming perforated by the arc, a jet of carbonic acid gas rushes out, which effectually puts out the arc. Experiments, with fuses only a few inches long, and carrying very heavy currents at 10,000 volts pressure, have been most successful.

Even at their best, however, fuses are, in many respects, inferior to magnetic circuit breakers. For instance, when a fuse has blown, it takes some time to replace it, as the old fuse has to be removed and a new one inserted. In the Ferranti type this is not difficult, as, by means of the handle shown in the illustration, the porcelain box can be withdrawn "en bloc," the terminals being of the spring clip pattern, and a spare fuse inserted. This, however, means having a number of spare fuses ready, and to hand.

H. T. Circuit Breakers.—With the circuit breaker nothing of this kind is necessary. Consisting, as it does, of a switch, which is tripped by a magnetic device, and opened by a strong spring, all that is required to be done is to pull down the handle or lever, and the circuit breaker is again closed and ready for work.

Circuit breakers for high-tension currents are of several types, those in which the arc is drawn out between carbon-contact surfaces, or under oil, and those in which the arc is gradually extinguished between two curved horn pieces. In this latter case, the fact that the arc always tends to rise is taken advantage of, the curvature of the horn pieces being so arranged that, as the arc rises, the length of the arc increases, until it is extinguished by the

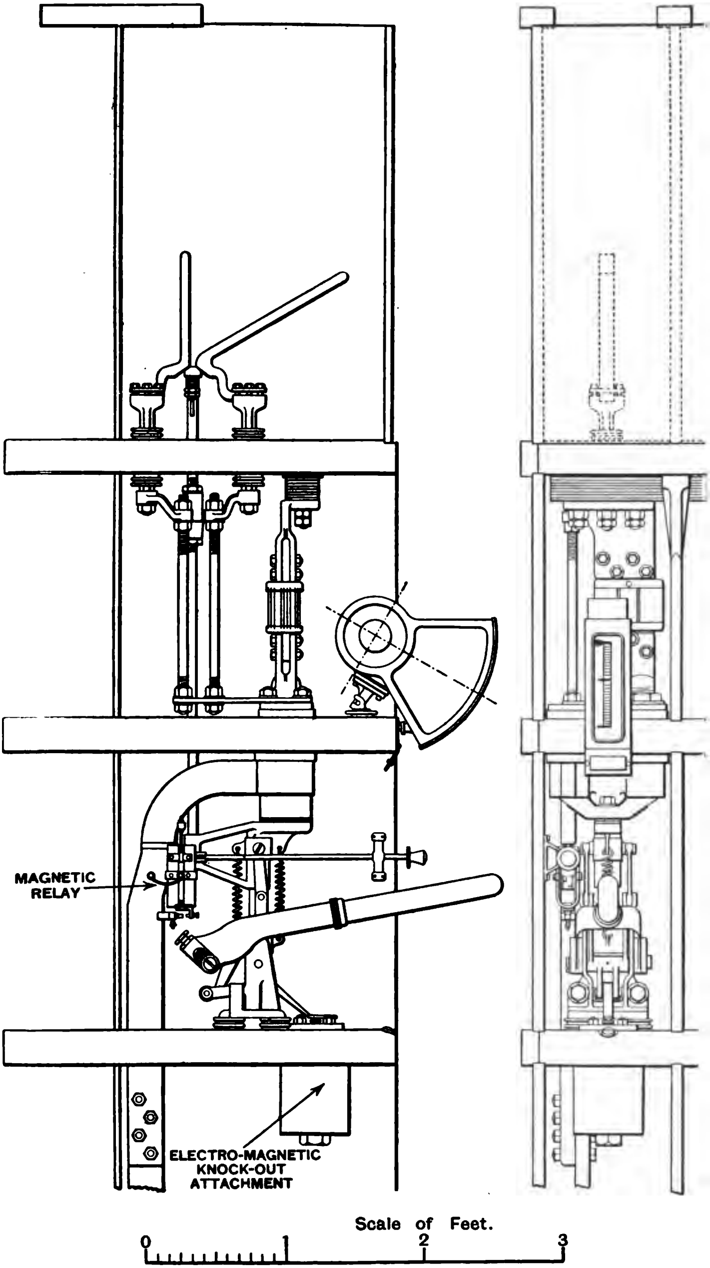


Fig. 24.—SWITCH GEAR WITH HORN CIRCUIT BREAKER.

mere reason, that the pressure behind it is insufficient to maintain it across the lengthened gap. Fig. 24 shows a switch gear with this type of circuit breaker.

When a fuse or circuit breaker has operated, and opened the circuit, it is generally because something out of the ordinary has happened on the circuit, and the opening of the breaker does not necessarily mean that the fault has been removed. In order, therefore, to guard the operator from any danger in replacing the fuse or circuit breaker, it is usual to open the hand switch as well. The operator, standing clear, replaces the fuse or closes the circuit breaker, before he closes the switch. The circuit breaker can then operate again, without danger, should a fault still remain.

Fuses should never be used on generator circuits, but circuit breakers which operate only with a return current of, say, 10% of the maximum value. The feeder circuit fuses should protect the generators from excess current.

H. T. Switches.—High-tension switches are merely circuit breakers, which are worked by hand, and not automatically. An oil break is frequently used, in order to extinguish the arc, but, when automatic circuit breakers, instead of fuses, are employed, it is often good practice to open the circuit only by means of the circuit breaker, which is usually provided with a hand trip gear. The switch proper is then only used in cases of emergency.

Oil break switches, excepting those of the Ferranti type, which are mounted in a slate recess, as shown in Fig. 20, are generally contained in cast-iron boxes, placed at some distance from the operating platform, and are worked either by connecting levers, compressed air, or motor gear.

H. T. Ammeters.—The two principal types of measuring

instruments, used in connection with high-tension alternating current switch gear, are ampère meters, commonly called ammeters, and voltmeters. These are merely indicating instruments, showing the current passing, or the pressure, at the instant. Ammeters, for alternating currents, are always of the electro-magnetic type, with a solenoid and iron plunger, or similar arrangement. To prevent any danger from touching an ammeter, which may be carrying high-tension currents, they are often worked from the secondary of a small transformer, the primary of which is in the main circuit. In the Ferranti type, however, the main circuit passes through the ammeter, which is specially well-protected and insulated. It is not necessary that an ammeter, in an ordinary switch gear, should be extremely correct, since its use is merely to indicate the current passing, and to act as a guide to the attendant, to show when a generator should be switched off, or a new one switched on.

H. T. Voltmeters.—A voltmeter, however, being used as an indicator of the pressure, which should be kept at a constant value, ought to be much more exact. Voltmeters can be obtained of several different types. We may have the magnetic type, similar in principle to the ammeter mentioned above: the hot-wire type, the elongation of a fine wire, under the passage of the current, being used as an indication: or the electrostatic type, in which two surfaces, charged with opposite potentials, are attracted to one another. This latter type is the only one which can be used directly on a high-tension circuit, the others requiring a small transformer, in order to reduce the pressure to an amount suitable for them.

Synchronisers.—The employment of alternating currents means the use of some apparatus to indicate when the

various generators are in synchronism. This makes the switching in of additional generators a more difficult task than when direct currents are used, since, not only must the pressure of the incoming machine be the same as that of the bus-bars, to which it has to be connected, but the alternating waves must be brought to exactly the same condition, before the switch is closed.

The pressure, varying as it does from a positive maximum to a negative maximum, many times per second, may thus be entirely opposed to the pressure of the bus-bars, and switching in "out of phase," as it is termed, may make not only a short circuit of the bus-bars, but even a short circuiting of twice the bus-bar pressure.

By using an apparatus, termed a synchroniser, it is possible to fix upon the correct moment, when the wave form of the generator is practically identical with that of the bus-bars. The synchroniser is a very simple thing, and may be of several different types. In most cases it consists of an incandescent lamp, or a voltmeter, connected so as to be operated by the incoming generator, and by the bus-bars at the same time. When the alternations are in unison, the lamp, or voltmeter, indicates the full pressure, and, when in opposition, no pressure is shown. In Fig. 25 is shown a diagram of the connections of a synchroniser. Two transformers are used, with independent primary coils, but with a common secondary coil. One primary is connected to the bus-bars, and the other to the incoming machine. It will readily be seen that, when the two primaries are working together, the secondary coil will give full pressure, and, when in opposition, that no pressure will result. As the incoming machine is speeded up, the pressure in the secondary coil will gradually become more and more steady, as the machines get into step, until,

Fig. 25.

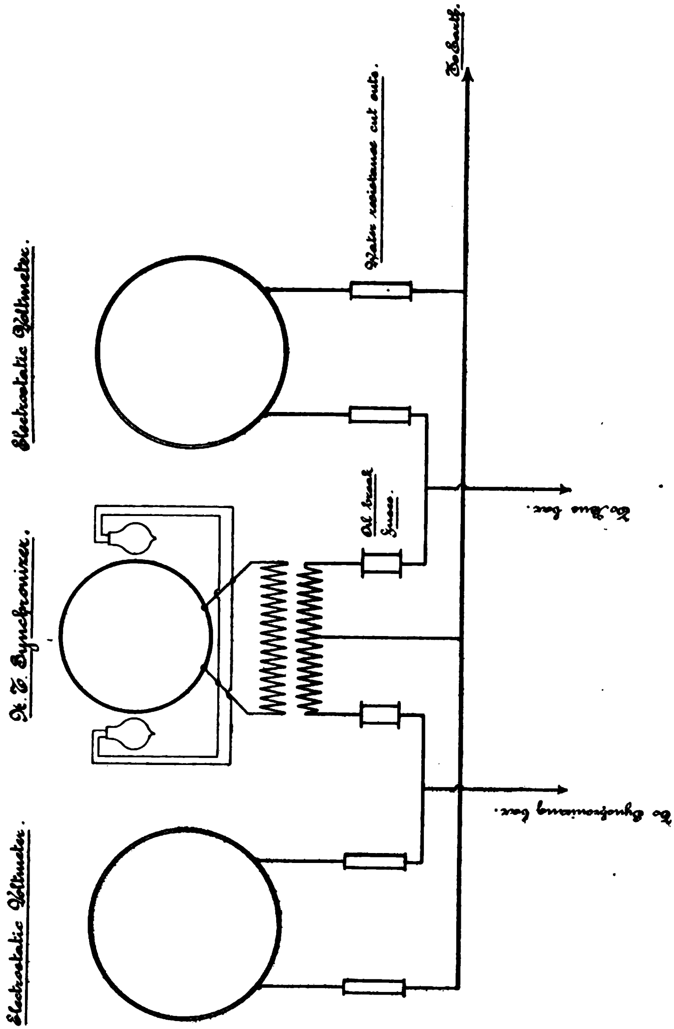


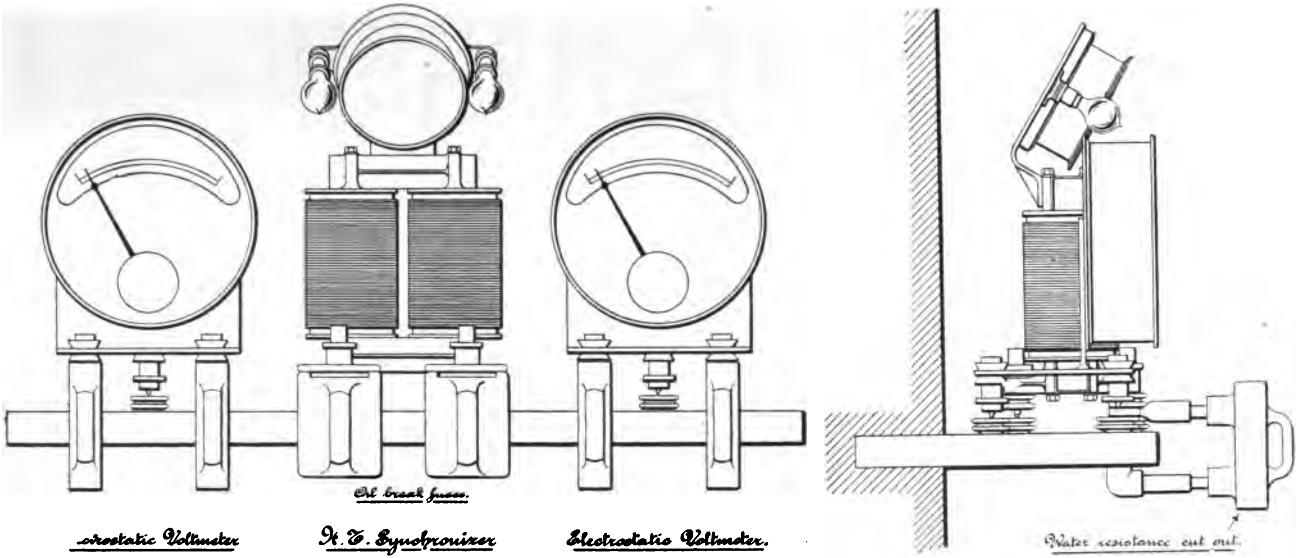
DIAGRAM OF SYNCHRONISER CONNECTIONS.

when the correct speed is reached, long intervals of full pressure, followed by long intervals of no pressure, result. When the beats become very long, and just at the instant that full pressure is indicated on the lamp, or the voltmeter, the switch is closed, coupling the machines in parallel.

Considerable practice is necessary, to determine the right instant for closing the switch, and, unless the engine-driver is also experienced in adjusting the speed of the generator, a considerable time may elapse before the proper moment is reached. It is thus necessary that the driver, as well as the switchboard attendant, should be able to see the indications of the synchroniser, and the incandescent lamps form the most convenient means for this to be done.

But the voltmeter forms a better indication than the lamp of the correct moment for closing the switch, because it will show small variations of pressure much better. It is usual, therefore, to provide both lamps and voltmeter for indicating the moment of synchronism. It is necessary, however, to use a voltmeter which is "dead beat," *i.e.* one which will show instant variations of pressure. For this purpose the moving parts must be very light, and the hot-wire voltmeter is about the best for the purpose. In Fig. 26 is shown a complete synchronising apparatus, as used with the Ferranti switch gear. The transformer, the lamps, and the voltmeter, are mounted together, in such a way that the indications are plainly visible, and the whole apparatus is remarkably neat and effective.

The indicator, shown in the above figure, is intended for single-phase machines, but can be used equally well for multi-phase machines, by placing it across one of the three



Front Elevation.

Side Elevation.

Fig. 26.—FERRANTI SYNCHRONISING SET.

windings of the machine. From the nature of the case it is evident, that, if synchronism be obtained between the two corresponding phases of different machines, the other phases must be in synchronism as well, since the sets of armature windings are equally spaced.

Divided Bus-Bars.—It is usual to couple all alternating current machines and circuits to a common pair of bus-bars, but, in large stations, where a great many machines may be used, it is sometimes advisable to divide the bus-bars into two or more sets, in order that it may not be necessary to run the whole station in parallel. That is to say, each set of bus-bars would have so many machines and circuits, the sets being connected together at times of light load, and separated at times of heavy load. In such a case, not only must there be a synchroniser for the machines on each set of bus-bars, but also a synchroniser to show when the different sets are in phase, so that they may be coupled together as the machines are taken off. In Fig. 27 is shown a diagram of such an arrangement for a single-phase system.

The synchroniser should only be brought into use when a new machine is to be switched in, and, in the Ferranti switch gear, this is done in a very simple manner. The generator switches are provided with what is called a synchroniser contact, shown in Fig. 27, and, when a machine is to be switched in, the switch is first placed on the synchroniser contact, which is very similar to placing a gun at half-cock. As soon as the moment of synchronism is indicated, the switch is pushed forward into the main contacts, breaking the synchroniser contact at the same time.

L. T. Switch Gear.—Low-tension switch gear has, so far, generally been of the flat board type, similar to that

described on p. 65. There being little or no danger to life in this case, the necessity for complete protection of the live contacts has not been felt. But the complications at the back of the panels certainly leave a great deal to be desired, and switch gear, on the same general lines as the Ferranti high-tension gear, is now being placed on the market.

With the exception of the synchronising apparatus, the

Fig. 27.

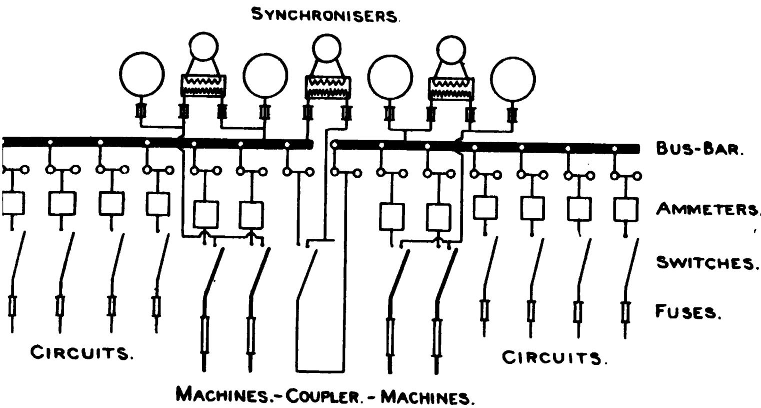


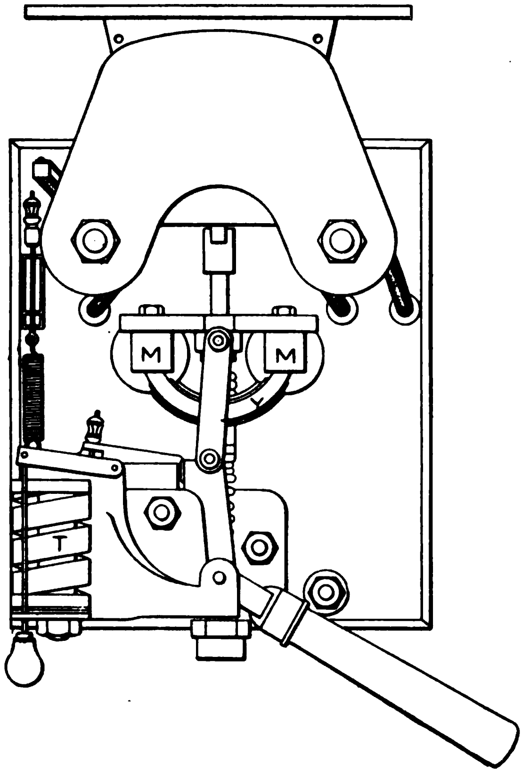
DIAGRAM OF DIVIDED BUS-BARS, WITH SYNCHRONISERS.

various parts of low-tension switch gear have, as was mentioned earlier, to perform similar functions to those of the high-tension gear, the use of direct currents of greater quantity, and lower pressure, necessitating modifications in the details of the apparatus.

L. T. Circuit Breakers.—Fuses are now seldom met with, circuit breakers being, practically, in universal use. The arc, occasioned by the breaking of a direct current circuit, is always more difficult to handle than that on an alter-

nating current circuit, since, in the former case, with a given pressure, it is much easier to maintain the arc.

Fig. 28.



MAGNETIC BLOW-OUT CIRCUIT BREAKER.

The action of a magnetic field is therefore frequently employed in order to blow out the arc, when the circuit is broken. It is well known that a magnet will deflect an arc, and, at the moment of breaking the contact, the

current is diverted through the coils of a powerful electro-magnet, between the poles of which the arc is broken. The effect of the magnetism is, therefore, to cause the arc to spread outwards, away from the contacts, and so to be readily broken. A well-known type of circuit breaker, on these lines, is shown in Fig. 28, and its electrical connections in Fig. 29.

Fig. 29.

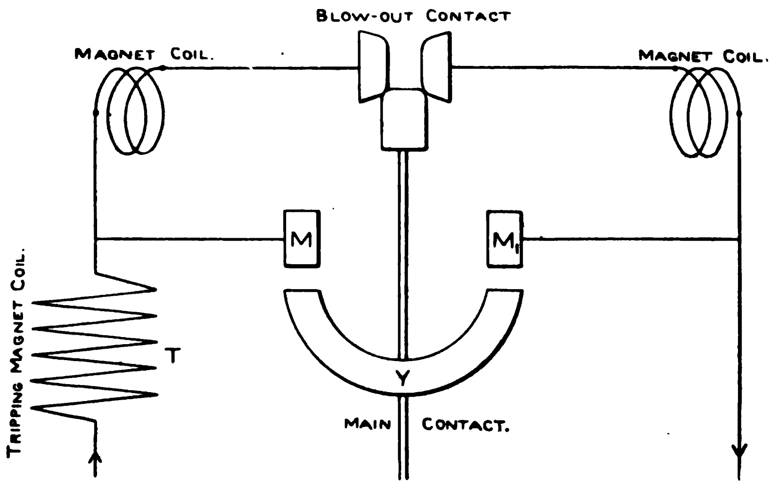


DIAGRAM OF CONNECTIONS OF BLOW-OUT CIRCUIT BREAKER.

There are various other forms of low-tension circuit breakers, which do not employ a magnetic blow-out, some breaking the circuit on carbon points, and others using curved horn plates, similar to those described on page 72.

L. T. Switches.—Excepting that switches for low-tension currents require much more massive contacts, because of the relatively large current carried, there is no essential difference between them and those used for high-tension

currents. Oil breaks are unnecessary, but in all cases the switches should be arranged with a spring break, independent of the main handle.

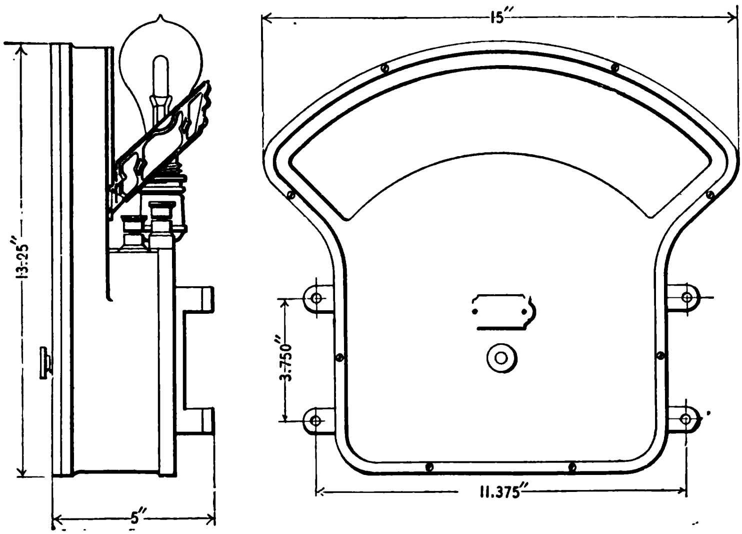
L. T. Ammeters.—The ammeters used with low-tension switch gear, being for direct currents, can employ permanent magnets in their construction. One of the best-known types is that of Mr. Weston. In this pattern a permanent steel magnet, with specially shaped pole pieces, is used, with a light-moving coil between them. When a current is passed through the coil, it tends to set itself at right angles to the lines of force from the magnet, against the controlling power of a spring. This instrument is remarkably dead beat. When used for anything but the very smallest currents, it is always provided with a shunt, through which the greater portion of the current passes. It would not be possible to wind a moving coil ammeter with a conductor of a size suitable for carrying the whole current, and the use of a shunt enables a fine winding to be employed.

Theoretically, a shunted ammeter is a voltmeter, which measures the difference of potential between the two terminals of the shunt. This, of course, varies in direct proportion to the current passing, and, therefore, the instrument, although really a voltmeter, can be calibrated to show ampères.

The current indicated by the shunted ammeter depends not only upon the difference of potential between the terminals of the shunt, but also upon the resistance of the ammeter circuit, of which the connecting wires form a part. This will explain why it is necessary to use always the correct ammeter and shunt together, and why the connecting wires, sent out with the instrument, must not be shortened, or lengthened.

L. T. Voltmeters.—Low-tension direct-current voltmeters are, in almost all cases, of the permanent magnet type, one of the most commonly used being that of Mr. Weston. This instrument is very similar to the ammeter described above, and it is, perhaps, one of the most largely used in

Fig. 30.



VOLTMETER, WITH ILLUMINATED DIAL.

traction schemes, being exceedingly reliable and correct in its indications.

It being necessary that the indications should be visible at night time, as well as during the day, a transparent dial, with an incandescent lamp behind it, is often used, and this pattern is a very favourite one, in connection with low-tension switch gear. It is illustrated in Fig. 30.

The generators and the circuits are usually coupled to one

set of bus-bars, so that it is only necessary to use two main voltmeters, one being connected to show the pressure on the bus-bars, and the other to indicate the pressure on any of the individual generators, by means of a multiple switch. These two voltmeters are always used in bringing a new generator into action, and are often mounted conveniently together on a swinging bracket, so as to be seen by the attendant at any point.

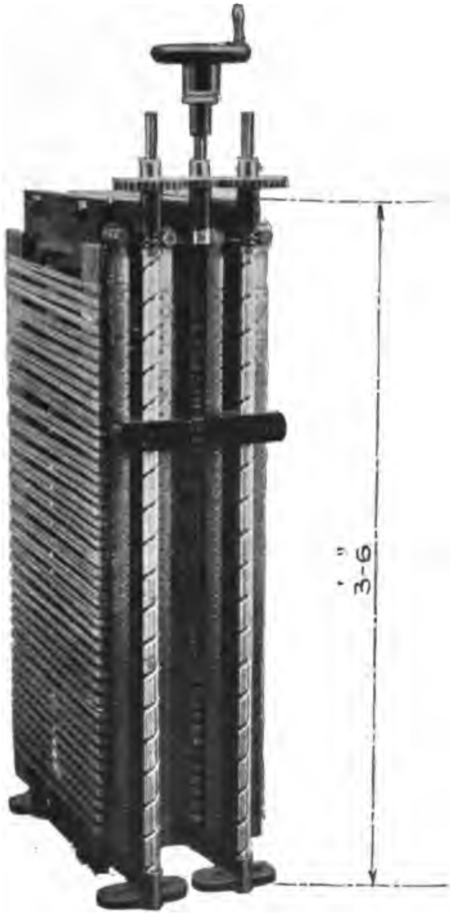
Field Resistances.—In order to maintain the pressure of the generators at its proper value, we must be able to adjust, not only the speed of the engines, but also the strength of the generator fields. This is always done by means of variable resistances in the field circuits. Too much attention cannot be given to obtain reliable resistances, since a failure may result in the throwing out of action, not only the generator to which the particular resistance belongs, but also the other machines which may be working in parallel with it.

One of the most common arrangements is to have a multiple way switch, with individual wires, from each contact, to the various points of the resistance. This, however, means a large number of small wires and connections, usually in a very cramped position, with great risk and danger of breakdown. To obviate this, a form of adjustable resistance is sometimes used, where the switch is mounted directly upon the resistance frame, the switch contacts being practically part of the resistance wire itself. A resistance frame of this type is shown in Fig. 31.

A cast-iron frame is provided, covered on the edges with suitable insulation, and around it is wound a bare resistance wire. On one edge of the frame is mounted a row of brass contacts, each contact being in direct connection with one of the turns of the wire. A sliding switch,

worked by means of a long screw and a hand-wheel, in a

Fig. 31.



FERRANTI FIELD RESISTANCE FRAME.

convenient position within the reach of the attendant

moves up and down over the contacts, thus bringing more or less of the resistance wire into the circuit.

As resistance wires always become warm in working, it is very necessary that they should be placed in a ventilated fire-proof position, away from the switch gear proper, a most convenient plan being to erect them in a room set apart for the purpose, immediately beneath the switch gear platform, the rod and hand-wheel coming up through the floor. Such an arrangement is shown in Fig. 20.

Field Switches.—Switches for breaking the field circuit are often used with tramway plant, and in many cases quite unnecessarily. The breaking of the field circuit of a large generator is a most dangerous operation, not to life, but to the insulation of the machine. A pressure of many thousand volts can easily be obtained, if the field circuit be broken suddenly enough. It is necessary, with alternating current generators, to use field switches when the machines are excited from a common source, such as a set of accumulators. But when each machine is excited from its own individual exciter, or when direct current machines are self-excited, there is no need to break the field circuit at all, and it is safer to do away with field switches altogether. When, however, they must be used, they should be specially made, to obviate any breakdown which may result from the self-induction of the field system. This can be done by such a switch as is shown in Fig. 32, where the field circuit is not opened at all.

The action of opening the switch puts a resistance across the terminals of the field coils, before the exciting current is broken. If this resistance be made of about the same value as the resistance of the field coils themselves, the exciting current can be broken without danger, and with the minimum of sparking.

Board of Trade Tests.—The Board of Trade requires certain tests * to be carried out on all electric traction

Fig. 32.

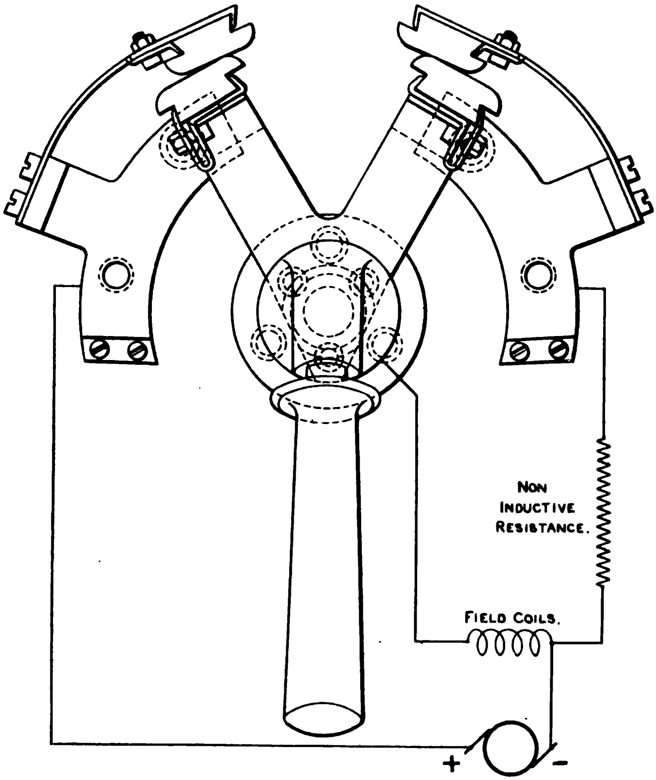


DIAGRAM OF FIELD SWITCH.

systems, some continuously, some daily, and others at longer intervals. It has become the practice to place all

* See Board of Trade regulations, in Appendix.

the apparatus for these tests upon a separate panel, which is called the Board of Trade panel. But such a course is not really necessary, as, by proper arrangement, the instruments required for the Board of Trade tests can be reduced to a very small number. Amongst them are recording instruments, which, in the Author's opinion, should be placed, not amongst the switch gear itself, but in a separate room, with the wattmeters and other integrating and recording apparatus. The switch gear instruments should be merely those of an indicating character, such as ammeters and voltmeters, since these are all which are required by the attendant, in order to regulate and control the various machines and circuits. The recording and integrating meters are really checks upon the attendant, and should be placed under the eye of the station superintendent, rather than the switch attendant.

The integrating instruments are simply meters for registering the total output of any particular generator or circuit, or of the station as a whole. The recording instruments furnish a continuous record of the pressure or the current, upon a paper chart, which is revolved by clockwork. The three classes of instruments thus constitute all that is required.

The indicating instruments show, by a pointer, the output at any instant, the recording instruments make a record in ink of the output at any instant, while the integrating instruments give the total output in units over any desired period, upon a set of dials.

Position of Switch Gear.—One of the most important points, in connection with the arrangement of the switch gear for any station, is its position in the engine-room. The switch attendant should be able to see to all parts of

the room, and be able to signal readily to the driver of any engine. The switch gear should be out of the way of the dangling chains of the overhead traveller, and it should be in such a position that the various cables, from the generators to the circuits, can be conveniently brought to it. By far the best position would appear to be in the middle of the long side of the engine-room, farthest from the boilers, as it is then at the shortest distance from all the machines in the room. If there be a gallery around the engine-room, the switch gear should be placed upon it, or, better still, in a recess opening on to the gallery, so as to be clear of the room proper.

The aim in designing and working switch gear should be to get the utmost simplicity and reliability, as its importance cannot be exaggerated in a large power station.

CHAPTER IV.

DISTRIBUTION.

General Principles—Copper Conductors—Fall of Pressure—Dimensions of Conductors—Pressure Limits—Effect of Increasing Pressure—Permissible Variations of Pressure—Economical Sizes of Conductors—Practical Methods of Determining Sizes of Cables—Site for Generating Station—Sites for Sub-stations—Boosters—Fall of Pressure on Uninsulated Returns—Return Feeders—Application of Booster—Three-wire System—Direct Current Sub-stations—Alternating Current Sub-stations—Cables for Three-phase System—Power Measurements on Three-phase System—Rotary Transformers—Motor Generators—Insulation—Methods of Laying Cables—The Solid System—The Draw-in System—Jointing Cables—Types of Cables.

General Principles.—The economical distribution of power, from the generating station to the different parts of the system, is, in a large scheme, perhaps the most important of all the problems which the electrical engineer has to face. In small systems, where the area of working lies within a two- or three-mile radius, the ordinary method of direct current generation and distribution suffices—the power being generated, at a pressure of from 500 to 600 volts, in one station as near as possible to the centre of the area. As the area to be served grows in size, difficulties of regulation and the heavy cost of conductors are immediately felt, if the direct current system, with one generating station, be still used. We can either put down a second station, to feed the outer

area, or, under certain conditions, we can use double the ordinary pressure, by means of a three-wire system.

For still larger systems, we must either multiply the number of stations, or else generate at high pressure, and feed the various parts of the system through local transforming sub-stations. Examples of all these methods are to be found in practice.

Before considering the practical methods of laying underground cables for traction purposes, we will go, somewhat in detail, into the problems connected with, and the calculations necessary in deciding upon, the correct method of distribution, and the economical sizes of cables.

Copper Conductors.—All conductors now used for transmitting electric power (with the exception of the track-rails) are of copper, and we need, therefore, consider no other. For underground cables the copper is usually soft-drawn, while for overhead conductors, in order to obtain tensile strength, it is hard-drawn. According to Matthiessen's standards, a copper conductor has a resistance as follows, viz.:—

$$\text{Soft-drawn copper} = \frac{\cdot 0423}{\text{A}} \text{ ohms per mile.}$$

$$\text{Hard-drawn copper} = \frac{\cdot 0432}{\text{A}} \text{ ohms per mile.}$$

where A = the cross-sectional area in square inches.

In practice we have to allow for slight variations in manufacture, and ·0435 is usually taken for both hard- and soft-drawn copper in the above equations. This figure will be found to agree very well with that of the various cable-makers.

In making calculations, it is very convenient to have our standards of lengths expressed both in miles and

1,000-yards, and the following table has been worked out for these lengths, using the standard of resistance above given.

Table 3.—RESISTANCES OF COPPER CONDUCTORS.

Area in sq. ins.	Resistance in Ohms.		Weight in lbs.	
	Per 1000 Yards	Per Mile.	Per 1000 Yards.	Per Mile.
·05	·494	·870	578	1,018
·1	·247	·435	1,157	2,035
·125	·1976	·348	1,445	2,544
·15	·1646	·290	1,734	3,052
·2	·1235	·2175	2,312	4,070
·25	·0988	·174	2,891	5,088
·3	·0823	·145	3,468	6,105
·35	·0706	·1242	4,049	7,122
·4	·0617	·1087	4,624	8,140
·5	·0494	·087	5,781	10,175
·6	·0411	·072	6,936	12,210
·7	·0353	·0621	8,099	14,245
·75	·0329	·058	8,672	15,263
·8	·0309	·0544	9,249	16,280
·9	·0274	·048	11,404	18,315
1·0	·0247	·0435	11,562	20,350

Fall of Pressure.—Were it not for the fact, that all conductors offer a certain resistance to the passage of electricity, there would be no trouble whatever in transmitting any amount of energy, for any distance, without any loss. But, unfortunately, a fall of pressure, and, consequently, a loss of energy, results, whenever current is passed through a conductor. Knowing the resistance of the cable, and the value of the current, the drop in volts can always be obtained by Ohm's law, viz.:—

$$\text{Drop in volts} = \text{current} \times \text{resistance},$$

while the power wasted is always equivalent to

$$\text{Power wasted} = \text{current}^2 \times \text{resistance}.$$

Dimensions of Conductors.—The usual way in which the problem presents itself is, to find what size of conductor is necessary, to carry a certain current, for a certain distance, with a given fall of pressure. This we may obtain readily by the following, viz. :—

$$\text{Area of conductor} = \frac{\cdot 0435 \times \text{current} \times \text{miles}}{\text{Drop in volts.}} \qquad (8)$$

To carry a given current with a fixed fall of pressure, it will be found that the cross-sectional area of a conductor increases directly with its length, and that its weight increases as the square of its length. If it be allowed that the car-service increases directly with the area of the district served, and that the total length of the feeders increases also directly with the area, then the weight of copper necessary will increase, roughly, as the cube of the area.

The weight of the conductor increasing so rapidly with its length, soon brings us to a point where the cost of the copper becomes prohibitive, and we must either put down a second generating station, near the area to be served, or else we must reduce the current itself by increasing the pressure.

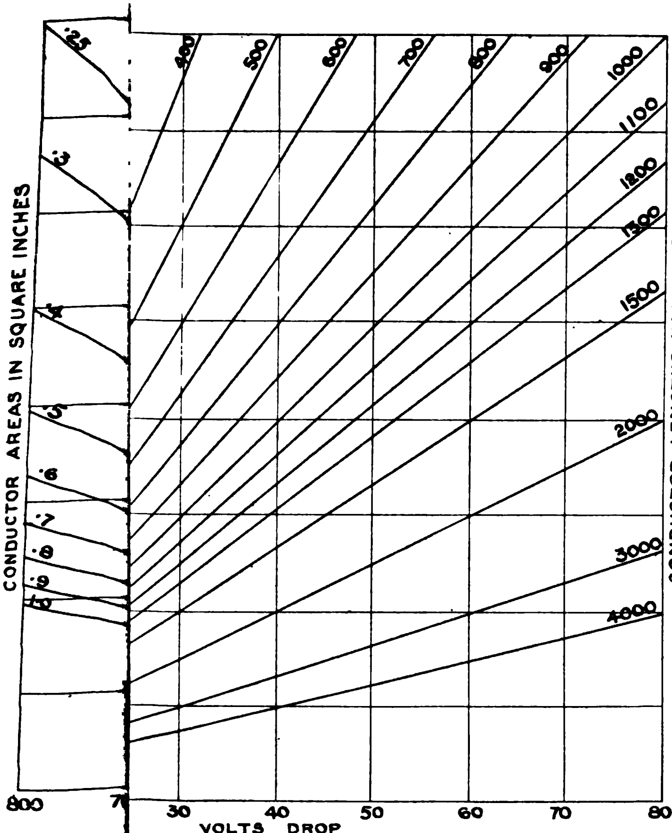
Pressure Limits.—The Board of Trade will not allow a working pressure higher than 550 volts on the line, and to work with a greater fall of pressure than 50 volts (or 10%) would be very uneconomical for such a "long-hour" load as a tramway. If, therefore, we adopt a higher pressure than, say, 600 volts at the generating station, we must have some means of reducing the pressure, before it reaches the line. This can only be done, in practice, by transforming apparatus of one kind or another, and so, when a pressure higher than 600 volts is used, it is usual to take advantage of the flexibility of the trans-

forming apparatus, and to increase the pressure to 2,000 volts or over.

Effect of Increasing Pressure.—The effect of increasing the pressure is, of course, to reduce the current in the same proportion, for a given amount of energy to be transmitted, and therefore the size of the conductor can be reduced likewise. Doubling the pressure will enable 4 times the amount of energy to be transmitted, with a given percentage loss. It will be seen that an important saving can be effected in distribution, by working at high pressure. To facilitate rapid approximate calculations, for finding the areas of conductors under different conditions, Fig. 33 is given. From it we are enabled to obtain the required area, for different values of current, and fall of pressure, and for various lengths. When the track-rails are used as the return circuit, their resistance must also be taken into account. This matter is dealt with more fully in Chap. VIII., where values are given, derived from practice, both for the rails themselves, and also for the complete track laid in place, with the various joints bonded together.

In using Fig. 33 for determining the size of trolley wires, or other conductors with a distributed load—*i. e.* with current taken off more or less evenly throughout their length, the effective current, so far as the fall of pressure at the extreme end is concerned, is only one half of the total current passing into the conductor.

Permissible Variations of Pressure.—Greater variations of pressure are permissible on a tramway system, than would be allowed on a lighting system, since the efficiency of a motor does not fall off, at anything like the same rate, as that of a lamp, as the pressure decreases. But, even on a heavily-loaded system, the variations in pressure



PRESSURE.

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should certainly be kept within 10%, say 5% up and down from the normal. If the current be supplied to the motors at a greatly reduced pressure, then the speed of the cars will be considerably lowered, and the value of the service much impaired. It may frequently happen that, at the end of a very long line, the pressure may be from 15% to 20% low, but in such cases it would pay to increase the size of the feeder to that point, or to use a booster.

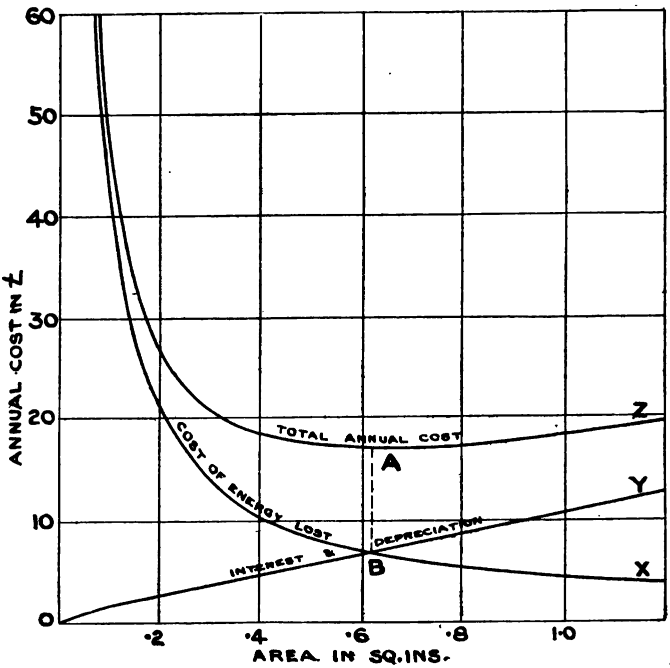
The maximum variations of pressure should be calculated on the maximum currents likely to flow, and, to determine these, temporary overloads, caused by a local congestion of the traffic, must be allowed for. To estimate what the temporary overload may be, requires very considerable experience, and, while the values obtained from Fig. 33, above, are quite true in themselves, they require to be used with much judgment and discretion, to determine correctly the best size for any given condition. To add to the difficulties, a very prophetic eye is necessary, to gauge the probable growth of the tramway system. It is frequently found that cables are laid down, suitable for only to-day's requirements, and almost before they have been brought into use, larger ones are necessary, simply because of the natural growth of the traffic.

Economical Sizes of Conductors.—In determining the correct size of cables, we shall have to take into account something more than the mere fall of pressure. While the fall of pressure means a continual loss of power, and consequently a cost for energy wasted, there are additional charges, which go on day and night, whether the cable be carrying current or not. These are the interest and depreciation charges on the cost of the cables laid in place.

Taking first the case of bare conductors, such as trolley

wires, or overhead transmission lines, the cost of such conductors is practically proportional to their weight, and, for a given percentage loss in energy, the cost of the lost energy is inversely proportional to their weight. If we

Fig. 34.



CURVE OF ECONOMICAL AREA FOR CONDUCTORS.

increase the cross-sectional area, and therefore the weight of the conductor, we increase its cost; but, at the same time, we decrease the fall of pressure, and therefore the loss of energy for the given current. The curve, connecting the relation between these two costs, is a hyperbolic

one, similar to the curve connecting the pressure and volume of steam or gas. In Fig. 34, this curve has been plotted, and is marked X. The curve, connecting the interest and depreciation cost with the area of the conductor, is practically a straight line, passing through the origin, O, in the figure, and having a definite slope depending upon the values. This curve is marked Y. The total annual cost is obtained by adding the two curves together, and it is shown, in the figure, by the curve Z. For conductors of small areas, this curve has a high value, becoming less as the size of the conductor is increased, and finally rising again. The lowest point, marked A, is directly above the point B, which is at the intersection of the curves X and Y.

Now the point of intersection of the curves X and Y is where the two annual costs, the one for energy wasted, and the other for interest and depreciation, are of the same value. We have then arrived at this rule for determining that size of conductor which will give us the least total annual cost, viz., "For a bare conductor, the most economical size, is that on which the annual interest and depreciation costs, are equal to the annual cost of the energy lost." This is known as Kelvin's Law, and, for the conditions stated, it is quite correct.

The economical size of conductor, for any case, is quite independent of the length of the conductor. This is readily seen, when it is remembered that the cost of a conductor, and also of the energy lost in a conductor, other things being the same, are both exactly proportional to its length. Therefore, as by increasing one factor, we increase the other in the same proportion, we have not altered the condition of things at all. Any other size of conductor, whether smaller or larger than the one given

by the preceding rule, would result in a greater total annual cost. As the economical area is independent of the length of the conductor, with very long conductors we shall get a fall of pressure much greater than 50 volts, or 10% on a 500-volt system. In fact, the limit distance for this loss, with this initial pressure, and with bare copper, is about 3¾ miles. If it were necessary to work for a longer distance, with the same fall of pressure, a larger conductor must be used, with some sacrifice of economy in working, or else some other system must be employed.

If, instead of using bare conductors, whose cost is practically in proportion to their area, insulated conductors be used, the case must be treated in a somewhat different manner. It may be at once definitely stated, that, with any kind of insulated conductor, there is a correct economical size for every particular case, but it is not exactly as given by Kelvin's Law.

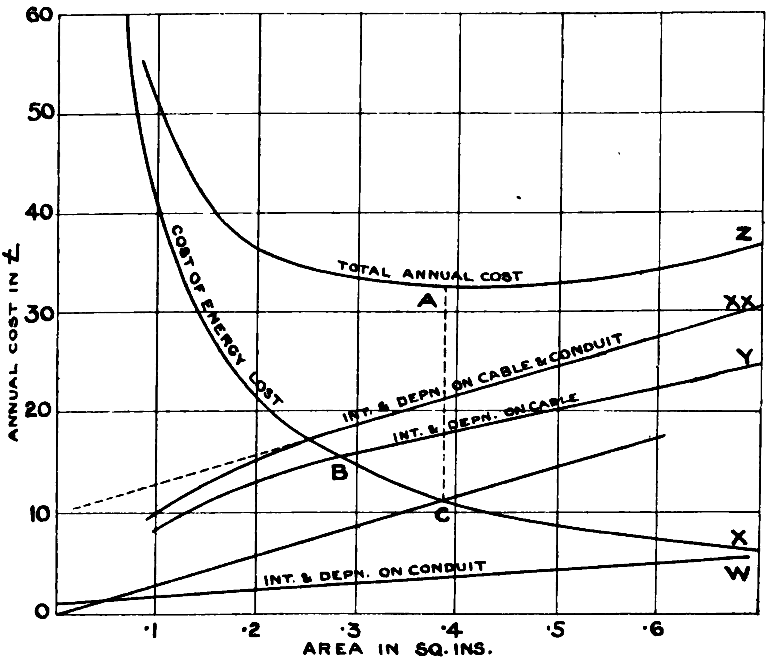
When conductors are insulated, it is always found that the cost of the finished cable becomes smaller, in proportion to its conductor area, as the latter increases. This, stated briefly, simply means that small insulated cables are dearer, after the rate, than large ones. The total cost of the cable is made up of the price paid for it to the maker, and also the cost of laying it in place underground, together with the pipes or ducts, if such be used. As a rule, the cost of laying is, within reasonable limits, the same for large and small cables, which still further emphasizes the comparative cheapness of the larger sizes.

Practical Methods of Determining Sizes of Cables.—The easiest way to find the most economical size of cable for any particular service is as follows. viz. :—

From the cable lists of reliable makers, take out the prices of a number of cables of different areas, with

insulation suitable for the pressure to be used. Having fixed upon the annual percentage charge per mile, for interest and depreciation (usually from 8% to 10%), construct the curve Y, Fig. 35. From the conditions of

Fig. 35.



CURVE OF ECONOMICAL AREA FOR LOW-TENSION CABLES.

running, and the cost of energy, construct the curve X, showing the annual cost of the energy lost per mile. With curve W, plot out the interest and depreciation on the cost of the laying of the cables, per mile, per annum. (If the cables be laid directly in the ground, there will be no

depreciation on this item, as no material, other than the cables, would have been used.)

By adding the three curves, Y, X, and W together, we shall obtain a fourth curve, Z, giving the total annual cost per mile for different sizes of cables, and the lowest point, A, will correspond to the most economical size of cable. It will be noticed that the point A is not directly over the point B, where the curves X and Y cross each other. Fig. 35 has been plotted for low-tension cables, and it will be seen that the total cost curve, Z, has a very flat portion near its lowest point, A, showing that the size of the cable can be varied over a considerable range, without material alteration of the total annual cost.

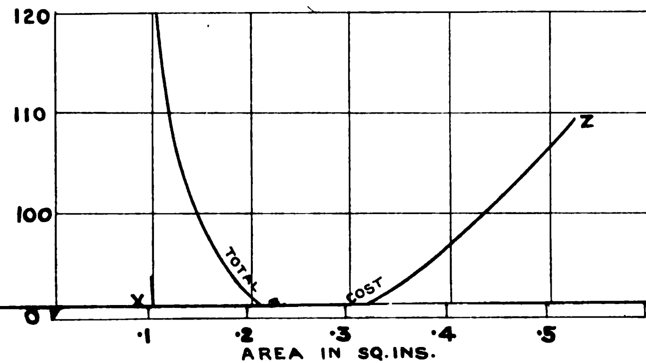
In Fig. 36 curves similar to those in Fig. 35 have been plotted for high-tension cables, which have much higher interest and depreciation charges. In this case the curve of total cost has a sharp U shape, showing a very limited range for the economical size, and that any divergence, in either direction, from it would mean a considerable increase in the annual cost.

It was shown in Fig. 35 that the point A, of lowest total annual cost, did not coincide with the point B, or the crossing of the two curves, X and Y. This is because the total cost curve includes a figure for the laying of the cable, as well as for the cable itself. We can, however, show that this variation from Kelvin's Law is more apparent than real. Let us add to Figs. 35 and 36 another curve, obtained by adding together curves W and Y. Call this new curve XX.

Draw, through O, another line, parallel to XX. This will cross curve X at the point C, which is directly under the point A of most economical size.

If the curve XX be not a straight line, then the line

Fig. 36.



CURVE OF ECONOMICAL AREA FOR HIGH-TENSION CABLES.

To face page 102.

through the origin, O, must be drawn parallel to a tangent to XX.

In all important schemes, the curves of total cost should be constructed, and the economical size of cable determined. The use of the economical size will mean a distinct annual gain, but, if by reason of excessive drop, the best size cannot be used, the curve will show clearly the extra annual cost of departing from that size.

In calculating the most economical size for a cable, carrying a current which varies largely at different parts of the day, the mean current must not be taken, because the energy lost depends, not upon the current, but upon the square of the current. The correct value to take, would therefore be the square root of the mean square of the current.

In Fig. 37 is given a diagram, which will facilitate the calculations for ascertaining the cost of the energy lost in the cable.

Site for Generating Station.—So far we have considered the subject as though only one feeder were used, but, in any actual case, there may be a large number of feeders, radiating from the generating station to local feeding points. On the plan of the district to be served, we can determine the feeding points for the different tracks, and denote at each point the load, or current, by means of a circle corresponding to it in area. We shall then obtain a number of different-sized circles, and their common centre of gravity can be readily found by well-known geometrical methods. It will be apparent, and it can be proved mathematically, that if the generating station (or sub-station) be placed at this point, the cables necessary to feed the various points will be at a minimum in length, area, weight, and cost, and whether bare or insulated.

Fig. 37.

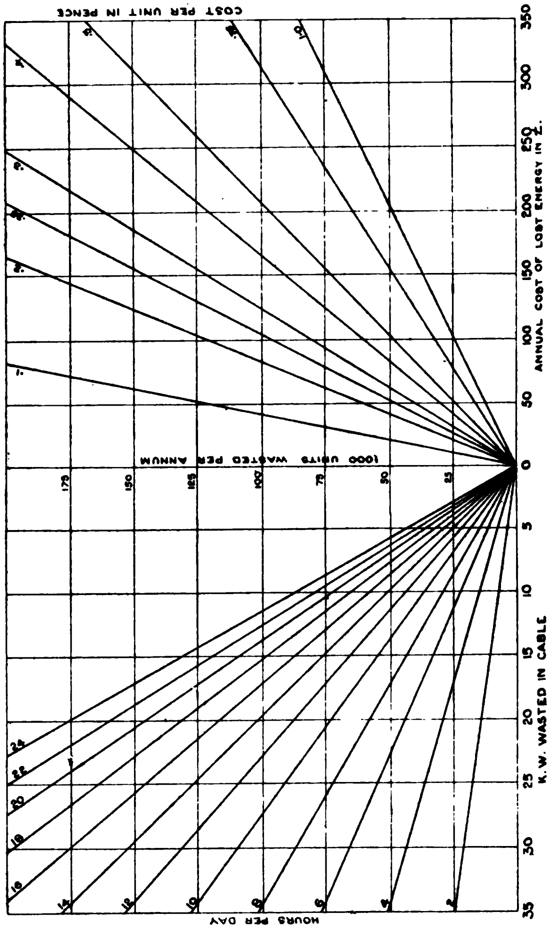


DIAGRAM SHOWING COST OF LOST ENERGY.

Unfortunately, as a general rule, this desirable spot for the generating station (from the point of view of the distribution of energy) is, very often, either entirely out of the question for physical reasons, or else a most unsuitable one, from the point of view of cheap generation. As a matter of fact, neither economical distribution, nor economical generation alone, can determine the best position for the station (although the latter is a much more important factor than the former, in consequence of the great latitude possible in the methods of economical distribution). So that, practically, our first consideration should be to select a site for the generating station, where cheap and ample land and water are to be obtained, and with good facilities for the cheap delivery of coal, and to make the system of distribution in accordance. In too many cases the opposite plan to this has been followed, with the result of uneconomical working, and great restriction of development.

Sites for Sub-stations.—In feeding a large area from a distant high-tension generating station, the same consideration, as was mentioned above, would indicate the most suitable positions for sub-stations. It is generally possible to obtain a site for a sub-station at a spot not far distant from the ideal position, since facilities for coal and water do not enter into the question, and cheap land only in a minor degree.

Having fixed upon the feeding points, and the position of the generating station, or the sub-station, and having determined the lengths of the distributing cables, with the currents they will have to carry, the most economical sizes of the cables can then be calculated. In so doing, due consideration should be given to the advisability of fixing upon standard sizes of conductors, uniformity of pressure

drop on the various sections, and the likelihood of extensions to the service.

Having to divide the line up into sections not exceeding half-a-mile in length, it is very convenient to feed each half-mile section direct from a sub-station or similar position. This means, for the overhead system, a separate positive cable for the line for each section, the rails being used as the return, and, for the conduit system, both a positive and a negative cable for each section, since in the latter case the rails are not used as conductors.

It may happen that one or two feeders are exceptionally long, and that the fall of pressure in them may be considerably over the economical limit allowed, unless cables of a very large size be used. In such cases it may be better to use a booster, for the purpose of raising the pressure on those lines, rather than to go to the cost of increasing the size of the cables.

Boosters.—A booster may be defined as a dynamo, which is used to add an E.M.F. to a circuit in which an E.M.F. already exists. It may be driven by an electric motor, a steam engine, or any other suitable means. Its armature is connected in series with the circuit in which it is desired to alter the pressure, while its field magnets may be excited in various ways, depending upon the manner in which the pressure is to be altered.

The use of a booster, to raise the pressure on long lines, is not necessarily the proper method in every case. The loss of energy due to the resistance of the cables is not removed, and, in addition, there are the internal losses in the booster itself. But, under certain conditions, it is the most convenient piece of apparatus to use.

Fall of Pressure on Uninsulated Returns.—It is shown in Chap. VIII., that the rails form a conductor of quite a

considerable value, and, in many cases, it is possible to use them, for bringing the whole of the current back to the station, without auxiliary return feeders.

On long lines, with heavy traffic, it is not always possible, even with heavy rails and good bonding, to use the rails only as the return conductors, since, with uninsulated returns such as the rails, we have to comply with a special Board of Trade regulation.* This regulation provides, that when any portion of the return circuit is uninsulated, the difference of potential, between the extreme ends and the points nearest the generating station, must be kept below seven volts. So, for other reasons entirely than those for economical working, we have to limit the fall of pressure in the return conductor, when the latter is uninsulated. This may be done by means of either (1) a sub-station, or (2) auxiliary return feeders, with or without return, or negative, boosters.

By dividing the system up into smaller areas, and feeding each area entirely through a sub-station, we practically reduce the length of the track. Such a method has been adopted, amongst other places, on the Dublin-Dalkey line, the Glasgow Corporation Tramways, the London United Electric Tramways, etc.

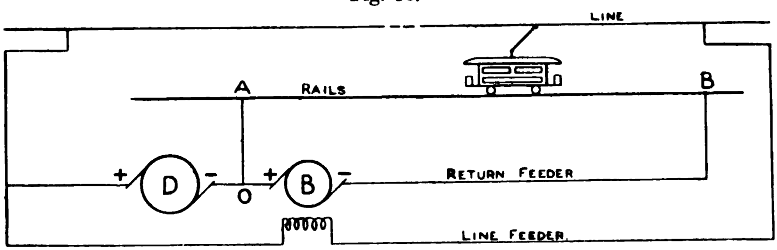
In all these cases rotary transformers are used in the sub-stations, driven by high-pressure, three-phase, alternating currents from the generating station.

Return Feeders.—The fall of potential in the rails may be reduced, by taking portions of the return current back through return feeders, laid alongside the rails, and connected to them at intervals. But, as the total conductivity of a double track, laid with 100-lb. rails, is about equal to

* See Appendix.

that of a copper cable of 3·5 sq. inches cross-section, it will be seen that such return feeders must be of enormous size to reduce materially the current flowing through the rails. But the apparent resistance of any conductor may be brought down to zero, and even below zero, by the inter-position, in the conductor, of an electro-motive force varying with the current flowing, and in such a direction as to assist the current to flow. Such an E.M.F. is most easily obtained by the use of a booster, such as was described above.

Fig. 38.



APPLICATION OF NEGATIVE BOOSTER.

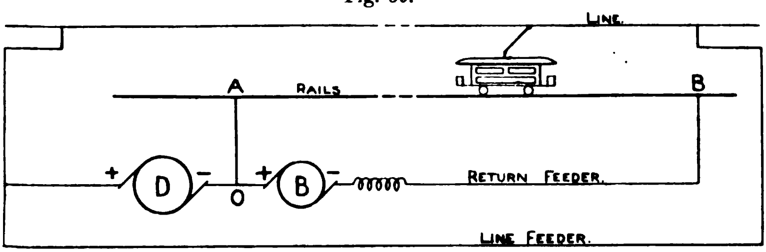
Application of Booster.—Fig. 38 shows the application of a booster to one of the return feeders of a tramway system.

In this case the power station is close to one portion of the track, A, which is here connected directly to the negative bus-bar, O. Another return feeder is run to a distant part of the track, B, and the difference of potential between the two points is found to be, say, 10 volts, when full current is flowing.

The booster armature is connected in series with the return feeder, and its magnets in series with the line feeder. Being driven at a constant speed by a suitable

motor, the booster will give a pressure in almost direct proportion to the current flowing into the line, and, therefore, to the current flowing through the return feeder also. It can thus be made almost exactly to counterbalance the fall of pressure in the return feeder, which is itself in direct proportion to the current flowing. The two ends of the return feeder, O and B, and therefore the two points of the track, A and B, can be kept at almost the same pressure, and the resistance of the return feeder rendered practically negligible.

Fig. 39.



INCORRECT USE OF NEGATIVE BOOSTER.

From its use in the "return," or "negative," feeder, such a booster is often called a "return," or "negative," booster.

When the track is a very long one, it may be necessary to use several return feeders, each with its own negative booster, and its corresponding line feeder. Where several boosters are in use in the same generating station, it is often convenient to mount them on the same shaft, with one motor to drive the lot.

Several instances have occurred of negative boosters proving useless, because the magnets have been connected in series with the return feeder, instead of with the line

feeder. At first sight, this difference may appear immaterial, since the same current is flowing in each. But a study of Fig. 39 will show the reason.

Since the negative bus-bar is connected direct to the rails at the generating station, the booster is working as a series dynamo, with the external circuit permanently closed, through the rails and the return feeder. It will depend entirely upon the resistance of this circuit, and upon the characteristic of the dynamo, as to what current will flow. But it is usually found that sufficient current

Fig. 40.

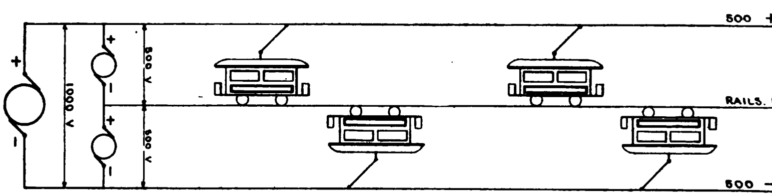


DIAGRAM OF 3-WIRE SYSTEM.

will flow continually,'round this closed circuit, to upset entirely any self-regulating properties of the booster.

Three-wire System.—We have seen that one way of reducing the loss of energy in conductors is to raise the pressure. This problem had already been encountered and, to a large extent, met, in lighting schemes, by the adoption of what is known as the "three-wire" system. By this system, the invention of the late Dr. John Hopkinson, we are enabled to use double the line pressure, without increasing the pressure at the motors. It is shown diagrammatically in Fig. 40, from which it will be seen, that if the current taken by the cars on each side of the system be the same, no current will flow through the

middle wire back to the generating station.* Such a system has the great advantage of enabling twice the ordinary working pressure to be used, without any transforming apparatus.

To use this system successfully, in tramway work, it would be necessary to keep the positive and negative conductors at a considerable distance from each other, in order that it may not be possible for any person to touch both, at the same time. In ordinary overhead construction, the three-wire system could not be used, as the conductors are usually too close together. But, by the use of the style of construction shown in Fig. 116, in Chap. IX., it would be quite possible to operate a three-wire system with success. The difference of pressure, between either wire and rails (or earth), would only be 500 volts, the pressure on the one side being above earth, and on the other below earth. The conductors would be too far apart for both of them to be touched at the same time by any person, and, excepting for a possible trouble in maintaining good insulation on the negative side, there would appear to be no objections whatever to its use. Special precautions would, of course, have to be used at junctions, and similar places, but the difficulties are by no means insurmountable. The rails would have to carry only a very small proportion of the total current, and the system could thus be used for very long distances, without any trouble, either from feeder losses or fall of pressure in the rails.

As they stand at the present time, the Board of Trade regulations will not allow the use of such a system, but it

* Unless the balancing of the load be perfectly done, locally as well as generally, there will be balancing currents through portions of the middle wire, although there may be none back to the generating station.

is difficult to see what danger to the public there would be, over the method now in use, as neither conductor would be at a pressure of more than 500 volts above, or below, earth.

In the case of tube railways, where each track is in a separate tunnel, the three-wire system should be almost an ideal one, as, with a well-arranged service, the loads on the two sides would balance, and the track losses be brought down to a minimum. On the City and South London Electric Railway, the three-wire system has been used with great success by Mr. McMahon, and, from his experience, there would appear to be but little difficulty in maintaining the insulation of the negative conductor. The comparative dryness obtained in the tunnels of underground railways may partly account for the little trouble experienced in this case, and, probably on systems where the conductors are exposed to ordinary weather conditions, the insulation of the negative conductor would prove more troublesome. An obvious method of improving this, would be to reverse the polarity of the whole system every few days, so as to give the insulation of the negative conductor (for the time being) an opportunity to improve itself.

Direct Current Sub-stations.—It was mentioned, earlier in this chapter, that, for very large systems, where the area to be fed is considerable, it may be necessary to generate at high pressure, and to feed the various parts of the system through local sub-stations. There are two methods by which this can be done. We may use direct-current machines in the generating station, and transform the pressure, at the sub-stations, by means of motor-dynamos or motor-generators. But the application of this method is very limited, since, with direct currents, a pressure of more than from 2,000 to 3,000 volts cannot be used,

on account of commutator troubles. This pressure is too low to be of much service, and, in consequence, we find that nearly all high-pressure transmission work is carried out by means of alternating currents, on a multi-phase system.

Alternating Current Sub-stations.—Either two-phase or three-phase currents may be used, but, for purely power purposes, such as we are considering, the latter has great advantages over the former. Pressures up to 11,000 volts have been used with underground cables, while, with overhead bare conductors, far higher pressures have been successfully employed, both on the Continent and in America.

Multi-phase generating plant has been described in Chap. II., and we need only now consider the question of distribution. At the sub-stations the high-pressure three-phase currents are transformed to low-pressure direct currents, which are fed directly to the tramway system.

With a compact area, the multi-phase system offers no advantages over the direct-current system, no matter how large the power generated. But, with a large scattered area, and with a generating station at a distant point, it is, at the present time, the only commercial one. One of its greatest advantages is its flexibility, as new areas can be most conveniently worked by another sub-station, fed by an additional high-tension feeder.

When fixing on the pressure for the generation, we must not consider the line (*i.e.* the high-tension feeders) by itself, since increasing the pressure beyond 6,000 or 7,000 volts will increase the cost of the generating and transforming plant, on account of the superior insulation thereby needed.

Cables for Three-phase System.—With the three-phase

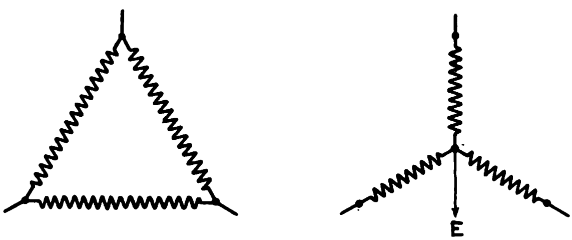
system, practically the only type of underground cable which can be used, is that with three separately insulated conductors, made up together into one cable, forming what is known as a three-core cable, as shown in Fig. 41. It

Fig. 41.

CROSS-SECTION OF 3-CORE CABLE.

will be seen that, as the pressure increases, while we may reduce the amount of copper, yet the extra thickness of the insulation necessary will increase the finished diameter, and also the cost of the cable.

Fig. 42.



MESH AND STAR CONNECTIONS.

The most economical pressure, at which to work, may be determined by calculating various alternative pressures, with their corresponding cost of plant and cables. There is no hard-and-fast line to be drawn, and, if a cheaper

insulation, with a higher breaking-down strength than the ones now in use, could be employed, the economical working pressure could very well be raised.

There are two methods of connecting up the windings of three-phase machines, known as the "mesh" connection, and the "star" connection. These are illustrated in Fig. 42, and, excepting for one condition, the use of either is immaterial, so far as the distributing system is concerned. When the mesh connection is used, there is the full difference of potential between any pair of the three conductors, and, if the insulation of each conductor be kept the same, then each will be at the same average pressure above earth. But, in practice, it is not possible to do this, and so each conductor must be insulated for the full pressure above earth.

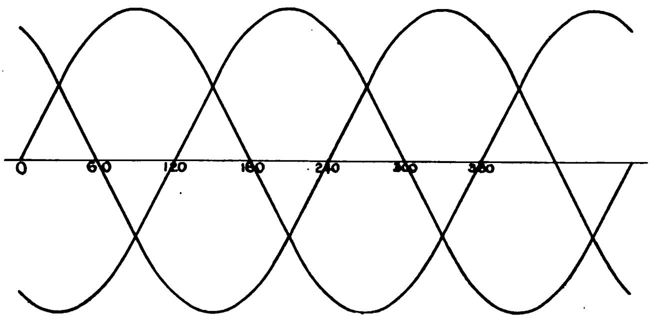
With the star connection, however, we may connect the common point of the three windings on the generator to earth, as is shown in Fig. 42. The result is, that each of the three conductors is kept at the same average pressure above earth, which cannot be greater than ·576 of the full working pressure (or $\frac{\text{Volts}}{\sqrt{3}}$). For this reason the star connection is the one usually adopted.

Power Measurements on Three-phase System.—As is well known, in alternating current systems, both the current and pressure change rapidly in value and sign, from zero to maximum, and to zero again. If the instantaneous values be plotted out, a wave-like curve is produced. This is shown, for a three-phase system, in Fig. 43. As both the currents and pressures are usually measured by instruments which depend upon the mutual action of two coils, what we measure is not the mean value, but the square root of the mean square, and this value, of both

current and pressure, is understood, when speaking of alternating values.

If, in an alternating current circuit, there be much self-induction caused by motors, transformers, etc., the current will not flow at the same instant that the pressure is applied, but there will be a distinct lag, and the pressure will reach its maximum value in advance of the current. The result of this is, that the power value will not be obtained by multiplying current by pressure, as with continuous currents, but we must multiply further by an

Fig. 43.



3-PHASE CURVES.

amount, varying from 1 to 0, called the power factor, depending entirely upon the value of the lag.

In a three-phase system we have :—

$$\text{Total watts} = \left\{ \begin{array}{l} \sqrt{3} \times \text{power factor} \times \text{current in each} \\ \text{conductor} \times \text{pressure between any} \\ \text{two conductors.} \end{array} \right. \quad (9)$$

And it therefore follows that—

$$\left.\begin{array}{r}\text{Current in each} \\ \text{conductor}\end{array}\right\} = \frac{\text{Total watts}}{\sqrt{3} \times \text{power factor} \times \text{pressure}} \quad (10)$$

The point of interest in the three-phase system is, that

although three distinct currents are being sent out, with a phase-difference of 120° between them, yet three conductors only are needed to transmit them. Each conductor, in its turn, acts as the return for the other two, the sum of the currents in two of the conductors always being equal in value, and of opposite sign, to the current in the third. This may be seen from a study of Fig. 43.

Rotary Transformers.—There are two methods of transforming high-pressure alternating currents into direct currents, at a lower pressure, in the sub-stations: (1) By means of statical transformers, in conjunction with rotary transformers; and (2) by means of alternating current motor-generators. The first method is standard practice in America, and the second on the Continent.

When rotary transformers are used, ordinary alternating current transformers are employed, to reduce the high-tension, three-phase, currents, to low-tension currents of about 350 to 390 volts, and the alternating currents, at this pressure, are led into one side of the rotary transformer, coming out at the other side as a direct current at about 550 volts pressure.

The rotary transformer is, usually, an ordinary multipolar dynamo, with commutator and winding of the usual type. But, in addition, connections are made to the armature windings at three equidistant points, and are taken to three insulated collectors, mounted on the shaft at the opposite end to the commutator. Fig. 44 shows the arrangement of the rotary and its transformers in a diagrammatical manner. If such a machine be driven as a dynamo, both direct and alternating currents may be obtained from the same windings, or, if driven as a motor, by either class of current, the other is produced.

The speed, at which a rotary transformer runs, will

depend upon the periodicity of the alternating current, and upon the number of magnet poles. In any case it will run synchronously, and must be brought up to speed before switching in. The starting may be done, either from the direct current side, or by means of a small motor coupled to the shaft. The ratio between the alternating pressure on the one side, and the direct pressure on the other side, will be about $1 : \sqrt{2}$; *i. e.* with 70·7 volts alternating, we shall get 100 volts continuous, and the current values will be in the inverse ratio.

Fig. 44.

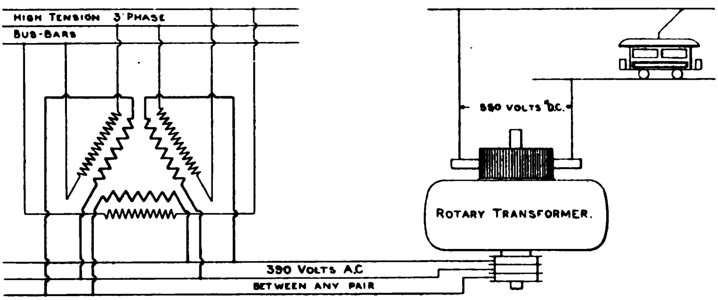


DIAGRAM OF 3-PHASE ROTARY, AND CONNECTIONS.

The chief value of this type of machine, when used as a transformer, is that it need only be large enough for the maximum (alternating) current, and the maximum (direct) voltage, instead of being equal to the combined input and output, as is necessary in the case of the ordinary double wound, or double armature, motor-generator.

When used for single-phase alternating currents, the machine has a number of disadvantages, which prevent its use, excepting for very small sizes. But, for multi-phase

alternating currents, rotary transformers are most successful, and there is practically no limit to the size to which they can be made. Machines of from 500 to 1,000 kilowatts output are in regular use in many places, and are doing excellent service.

The most usual periodicity for the alternating current, when rotary transformers are used, is 25 complete cycles per second, and, at this periodicity, there is no trouble from sparking. But, when the periods are as high as 50 cycles per second, the number of magnet poles is increased considerably, with the result that the number of commutator sections, from brush to brush, is very small. Flashing is likely to take place, and, for this reason, it is usual to work rotary transformers at a periodicity not much above 25 cycles per second.

The rotary transformer has only one field-magnet system, and its use is to balance the E.M.F.'s in the windings, and also to maintain the rotation. The field excitation should be set at that point which gives the least armature current on the alternating side, together with the least sparking. It is possible to regulate the direct current voltage over a considerable range, by varying the field strength, so as to control the phase relation. With a weak field, the alternating current will lag, and the direct currect voltage will fall. An over-excited field, on the other hand, will cause a leading alternating current, and an increase in the direct current pressure. Speaking generally, however, the regulation of the latter can only be satisfactorily done, either by an adjustable transformer, or by a resistance, in one or other of the main circuits.

Against the lessened cost of the rotary transformer, compared with the alternating current motor-generator, there has, of course, to be set the cost of the statical trans-

formers, and these must be large enough for the full output. They also have their own transforming losses, which must be added to the losses of the rotary transformer. But, notwithstanding this, the cost of the rotary transformer system is less, and its efficiency is higher, than the motor-generator. The relative merits of the two methods of transformation are much discussed at the present time, and each has its own particular advantages. Where facility for regulation is demanded, the motor-generator is without doubt the superior.

Motor - Generators. — The motor - generator consists generally of a synchronous alternating current motor, coupled direct to a direct current dynamo. It gives us the advantage of being able to transform to any ratio, without the addition of statical transformers, since the motor can be wound to take the full line pressure (up to, say, 10,000 volts). The facilities for easy regulation are much greater than with the rotary transformer, as the field, on the direct current side, is quite distinct from that of the alternating motor. If the latter be a synchronous one, it must be brought up to the correct speed before being coupled to the alternating mains, and this is usually accomplished, as with the rotary transformer, either by using the direct-current side as a motor, or by the addition of a small auxiliary starting motor. Many persons, however, prefer to use an induction motor, as described in Chapter XIV., p. 403, instead of a synchronous motor. The combination can then be started either from the direct or alternating current side.

Insulation.—All conductors, which are used to transmit electricity, must be covered with a continuous insulating material, unless they are carried upon insulated supports. Examples of the latter may be found, in overhead systems

of transmission and distribution, in bare copper strip for low-pressure currents, laid in culverts, and in the conductor bars of a conduit tramway system. But, for the very large majority of schemes, insulated cables are a necessity.

In the early days of electricity supply, indiarubber held a leading place as an insulator for cables. Experience has shown, however, that it is very liable to deteriorate, and that, for permanent work, it cannot be relied upon. Vulcanized bitumen has been very successful as an insulator for low-pressure work, but, for high pressures, paper holds the field, at the present time. Both rubber and bitumen are non-hygroscopic, but paper and such like substances have to be covered with a metallic sheath in order to keep out moisture. Lead is always used for this purpose.

Methods of Laying Cables.—It is hardly within the province of this work to go into any great detail regarding the various methods of insulating cables, but the way in which they are laid under the ground deserves our careful consideration. Being buried, and out of sight, it is seldom that the engineer gives a second thought to his cables, unless something goes wrong with them. It is possible to duplicate plant and machinery, in order to guard against a breakdown, but, with cables, this is only possible to a very limited extent. The distribution system is the connecting link between the generating station and the work, and too much attention and care cannot be given, to ensure its thorough reliability.

There are two chief methods of laying cables, one being called the "solid" system, and the other the "draw-in" system. Each has its own advocates, who hold that their system is the only proper one. But both systems have

their own peculiar advantages and disadvantages, and each may be used with success, according to circumstances.

The Solid System.—The solid system may be used in several ways: (1) By laying the cables directly in the ground, with no protection other than that afforded by their own covering. (2) By laying the cables in wood, earthenware, or iron troughs, and then filling the troughs up solid with a melted bitumen compound.

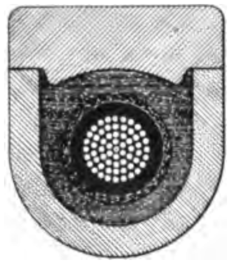
When cables are laid directly in the ground, they are usually protected by a couple of layers of steel tape, laid on over the insulation and the lead, when the latter is used. In certain soils, particularly those free from any trace of sulphur, such cables have been used with great success. One of their chief merits is the ease with which they can be laid, as they can be diverted at any point to clear obstacles.

In many instances these armoured cables are left entirely unprotected, but some engineers prefer to lay a line of old bricks, or lengths of tarred timber, directly over the cable, before the soil is entirely filled in, in order to give some kind of warning, or indication, to those opening the road at a later date, that there are cables lying underneath. While the steel tape will protect the cable from ordinary damage, it will not resist a heavy direct blow from a sharp pick, and the bricks or timber give a warning which is often very necessary.

When cables are laid in troughs, they do not require to have any armouring at all, as the troughs afford sufficient protection. When made of wood, the troughs should be thoroughly tarred with Stockholm tar, and a wooden cover is placed on the top, after the cable is in place, and the bitumen poured in. Small wooden bridges are placed at intervals along the bottom of the trough, in order to raise

the cable, and to allow the bitumen to flow all around it. A type of trough, shown in Fig. 45, has recently come into use, made of glazed stoneware with a cover. This

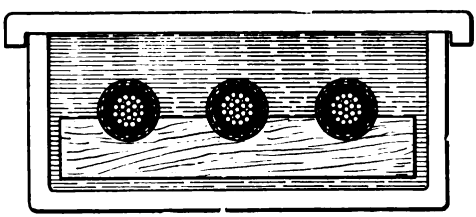
Fig. 45.



STONEWARE TROUGH FOR SOLID SYSTEM.

has some advantages over the wooden trough, as it is not liable to rot. A third, and more common, method is to make the trough and its cover of cast-iron, as shown in Fig. 46.

Fig. 46.



CAST-IRON TROUGH FOR SOLID SYSTEM.

Several cables can be laid in one trough, by having it of sufficient width, but it is not usual to provide for more than the lead and the return, or for the three wires of a three-wire system, in any one trough.

One of the chief advantages of the solid system is, that the cables remain directly in sight, after they are laid, until the final filling-in of the soil or the bitumen. Any accident, which may have been caused during the laying, can thus generally be detected before the cables are covered up. But, unless sufficient cables for all future requirements are laid down at first, it is necessary to re-open the whole length of the road, in order to lay any additional cable. Such a condition, in many instances, prohibits the use of the solid system, as, excepting for distributing cables, which can generally be reckoned beforehand, it is practically impossible to make provision for all that may be required in the future. The Author has found that, speaking generally, the draw-in system is the better one to use for feeder cables, or those which go direct from the generating station to the feeding points, and are not tapped on the road. For distributing cables, however, which go from the feeding points to the customers (in the case of a lighting system, at any rate), the solid system is the best. One particular reason why the feeder cables should be on a draw-in system, is because new feeders, going to new districts, generally have to pass along roads where cables are already laid, and, by providing a sufficient number of spare ducts in the original scheme, the new feeders can be pulled through, without disturbing the ground in any way. The distributors, however, for the new areas, can be laid when the tracks are being put down, and, therefore, without any additional opening of the streets.

The Draw-in System.—The ducts used for the draw-in system are of many types. For a number of years, cast-iron pipes were the favourite, being laid and jointed in 9-ft. lengths, like ordinary gas or water pipes. Of later

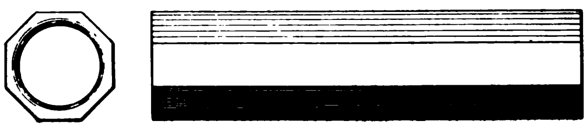
years, however, stoneware has been very largely used, either in the form of ordinary drain pipes, of 3 in. or 4 in. internal diameter, or of stoneware butt pipes, or of the so-called "Doulton" casing, in which a number of ducts are made up into one block. The cost of handling the latter is less than either of the former, but, on account of

Fig. 47.

DOULTON STONEWARE CASING.

the high price charged for the casing, it is in many cases being superseded by the stoneware butt pipes. A length of Doulton casing is shown in Fig. 47. It is made in either 2 ft. or 3 ft. lengths, with a number of ducts varying from two to half-a-dozen, and with the size of the hole varying from 2¼ in. to 4 in.

Fig. 48.



STONEWARE SINGLE DUCT.

A good form of stoneware butt pipe is shown in Fig. 48. This is similar to that adopted by the G. P. O., for the underground mains of their telephone system, and, by the Author, for the large distributing system of the London County Council electric tramways. These ducts, being octagonal in cross section, can be built up in blocks of any

desired number. They are generally laid on 3 in. or 4 in. of concrete, with the various lengths breaking joint, the whole block being surrounded by concrete, in addition.

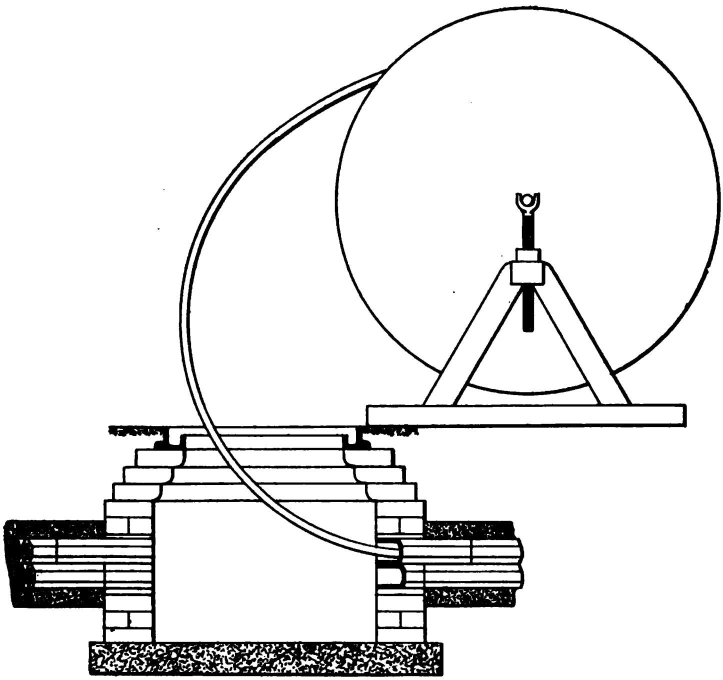
Stoneware ducts have one great advantage over iron pipes, as the Board of Trade requires that all metal pipes shall be jointed and connected, across all openings (*i. e.* joints), so as to make good electrical connection throughout their length. This is on account of the likelihood of any isolated length of pipe becoming charged, which is obviously not possible when the pipe is of a non-conducting substance, such as stoneware.

The depth at which cables are laid in the ground depends very much upon local conditions. They should, in all cases, be laid underneath gas and water service pipes, and the usual depth is from 2 to 3 ft. below the surface. Cables, which are laid directly in the ground, require a long length of street to be opened at one time, as the drum, containing the cable, must be mounted at one end of the trench, and the cable laid, or threaded, into place, before the soil is filled in. But, with the draw-in system, the ducts, being in short lengths, can be laid and covered over immediately. At intervals of from 50 to 100 yards, draw-boxes are built in the line of ducts. These boxes should be at least from 3 ft. to 4 ft. square inside. They are generally built of brick, with an iron roadway, or footpath, cover. The ducts finish off at the wall of the draw-box, and should be provided with some kind of bell mouth, in order to ease the entrance of the cables.

In some cases, small steel draw-wires are threaded through the ducts, as they are laid in place, to be used afterwards for hauling a rope, and then the cable, through when required. But, if the ducts be laid with care, such

draw-wires are unnecessary. It is much better to rod the ducts, or to thread a No. 8 galvanized iron wire through, when ready for the cable laying. If the ducts have been laid properly, no difficulty will be experienced in doing this, while, if draw-wires be left in the ducts, for any

Fig. 49.



MOUNTING DRUM FOR DRAWING-IN SYSTEM.

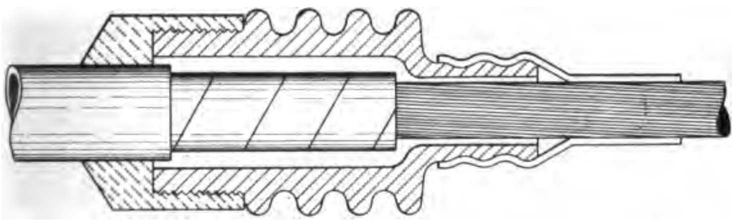
length of time, it will generally be found, that when they are required for use, they have rotted, and become broken in several places.

In drawing in cables, the drum should be mounted upon an axle, supported by adjustable screw jacks, so as to lift

the drum from the ground, and to allow it to revolve freely. The hauling rope, having been threaded through the ducts, from one draw-box to the other, is attached to a small hand winch, or is hauled by a number of men. At the other end it is attached to the cable, and then the pulling in can begin. A deal of discredit has been brought upon the draw-in system, because of the damage often done to the cables during the process of laying. In fact, the cables often suffer more damage at this time than in all their after life. To avoid this damage, great care is necessary, and there are two or three main points which must be carefully watched. The draw-boxes must be made large enough, particularly in the direction of their length, so that the cables may be led into the ducts, without any serious bending. Fig. 49 shows the correct method of mounting the drum, and the way in which the cable should be taken off it, and led into the ducts. In pulling the cable through a straight line of ducts, a distance of more than a hundred yards can often be pulled at once, if the cable be not too heavy, a man being stationed at an intermediate draw-box, if necessary, to ease the cable along. When the length of cable on the drum exceeds that which it is possible to pull in at one time, then the leading end of the cable must be taken right out of the far draw-box, and a fresh start made. It is particularly here that damage is done to the cable, as it has to be laid out along the road, before the end is brought back to enter the next line of ducts. For this reason, it is often well to limit the lengths, particularly of large cables, to those requisite to reach between, say, not more than two or three draw-boxes, and to make the joint in the draw-boxes after the various lengths have been pulled in.

Jointing Cables.—There are various methods of jointing cables. With rubber cables, the conductors are spliced and soldered, and the insulation is completed by vulcanizing rubber strip over the joint when made. With lead-covered cables there are two methods, one employing a cast-iron box, in which the conductors are clamped together, the interior afterwards being filled up with melted bitumen, or resin oil. In the other the conductors are sweated together, and a large lead sleeve slipped over the joint, being wiped to the lead of the cable on either

Fig. 50.



CROSS SECTION OF END CONNECTOR.

side, the interior of the sleeve being afterwards filled up with bitumen or resin oil as before.

Lead-covered cables require special end connections, in order to guard the insulation against the advent of moisture, and to bring out the conductors for connection. Fig. 50 shows a cross section of a well-known type of end connector.

Types of Cables.—Cables are usually distinguished as single, twin, double concentric, triple concentric, or triple core, depending upon the number of individual conductors and their arrangement. For alternating currents, either twin, concentric, or three-core cables should be

used, in order to balance the magnetic effects of the currents within the cable itself. For direct currents, either single cables, twin cables, or three-core cables may be employed, depending upon the method of distribution. Concentric conductors are really only suitable for systems of distribution, in which one conductor is permanently connected to earth, since the outer conductor of a concentric cable always tends to get to earth potential. For a single-phase alternating current system, such a cable is far and away the best, but, for electric traction purposes, we are confined, practically, to single conductors for direct currents, and to three-core cables for high-pressure three-phase alternating currents.

CHAPTER V.

MOTORS.

Conditions of Service—General Features—Rating of Motors—Motor Curves—Motors in Series and Parallel—Motor Construction—Magnets—Armatures—Commutators—Brushes—Gearing—Bearings—Lubrication—Motor Suspensions—Motors for High Powers—Motor Inspection.

Conditions of Service.—Electric motors are now used for a great variety of purposes, but electric traction makes by far the greatest demands upon the designer, because of the onerous conditions under which the motors have to work. In consequence of the restricted space in which the motor can be put under the body of the car, its size must be kept small. Having to run in either direction equally well, it must have a fixed brush position, and it must run sparklessly with great variations of current. The constant starting and stopping of the car calls for overloads of several times the normal output of the motor, while the windings and insulation must stand a pressure of between 500 and 600 volts, under all conditions of weather.

The motor must be able to work all day, without any attention whatever, and the windings must be secured so as to withstand the severe stresses due to sudden starting and stopping, and to the vibrations of probably a bad track and worn gearing.

That traction motors will meet these conditions, in a

thoroughly satisfactory manner, is a high testimonial to the ability, both of their designers and their constructors.

No attempt will be made, in this work, to enumerate the various stages through which the designs have passed, before the modern traction motor has been reached. The credit for the larger portion of the improvements, which have taken place, must undoubtedly be given to the engineers who have been associated with the great American electrical companies. The reason of this is largely due to the immense developments which have been rendered possible on that Continent, owing both to national characteristics and to the large field which is open there.

General Features.—At the present time, the designs of the leading makers have become very much alike, the conditions, under which traction motors in the various parts of the world have to work, being very similar: The general description following will therefore be applicable to all in a greater or lesser degree.

Excepting in a few cases, where older types are still employed, all tramway motors are arranged to work in pairs, and have series windings on the magnets. At starting, the motors are always coupled in series, and thus a full torque is obtained without an excessive current, while the strong magnetic field, due to the series coils, assists in sparkless working, even with considerable overloads. This matter is dealt with more fully in Chap. VI., where the various methods of connecting up the motors are gone into.

The armatures are always drum-wound, and run in a 4-pole field, with magnet coils on each pole. The external case of the motor is of cast steel, and it encloses entirely the whole of the working parts. The speed of the armature is usually between 800 and 1,000 revolutions

per minute, when the car is running at 16 miles per hour, and with 30-in. wheels. The speed is reduced by single gearing, with a ratio of 1 to about 4 or 5, the gearing consisting of a machine-cut steel pinion on the motor axle, and a similar spur-wheel on the driving axle.

The greatest improvement, which the motor has undergone in recent years, is in the use of former-wound armature coils. The commutator is now of very substantial construction, and much greater attention is paid to the insulation. To assist in obtaining sparkless running, carbon brushes are used, with heavy metal holders, the brushes being pressed radially on to the commutator by means of strong springs. The complete armature must be in true mechanical balance, and it is an advantage for it to have a very small fly-wheel effect, owing to the constant variations of speed.

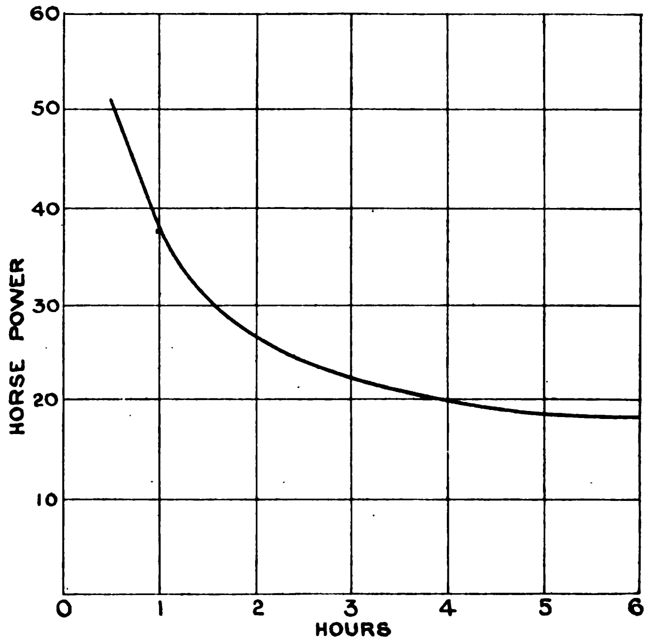
The points which have helped, above all others, to make a successful tramway motor, are (1) high permeability steel castings for the fields, (2) slotted armatures, (3) former-wound coils with waterproof insulation, and (4) carbon brushes.

Rating of Motors.—Owing to the constantly varying load upon the motor, the rating is very difficult to fix. The output is limited both by the sparking and the heating, and these limits may be reached in different ways. As was shown in Chap. I., the load on the motors, when starting and accelerating, may amount to several times the normal running load, but it only lasts for a few minutes, and sometimes even seconds. In this case the sparking limit will first be reached, and especially is this so when the motor is used as a brake, with reversed field connections, and an almost short-circuited armature.

When, however, the car is ascending a long incline, or

is hauling a heavily-loaded trailer car, the heating limit is reached much sooner than the sparking limit, since the normal current is kept on for a long period. It is obvious that, for a fixed temperature rise, the load, which may be put on the motors, will depend entirely upon the length

Fig. 51.



MOTOR CURVE CONNECTING H.P. AND TIME.

of time that it continues. This is clearly shown in Fig. 51, where the relation between H.P. and time, for a given motor, and for a given rise of temperature, is plotted.

It will be seen that at 18 H.P. the curve becomes horizontal, showing that the motor losses are balanced by

the radiation, and this rating is the output for continuous working. For a short period, however, many times this output could be taken, being limited only by sparkless commutation. The usual method, with a tramway motor, is to rate it at that particular load which corresponds to a rise in temperature of 135° Fahr., above the surrounding air, after one hour's working at that load. Instead of giving the output of a motor in H.P., it is generally more convenient to speak of it in terms of draw-bar pull, or tractive effort, with car-wheels of a given diameter, and with the car travelling at a certain speed in miles per hour.

The speed, at which the motor runs, is always such that the back E.M.F., plus the volts lost through the resistance of the windings, is equal to the voltage applied at the terminals of the motor. By increasing the number of turns on the armature, we decrease the speed, since the back E.M.F. is then obtained at a lower speed. Traction motors are always supplied with current at a constant pressure, and the current which passes through the motor will therefore vary nearly in the inverse ratio to the speed of the motor.*

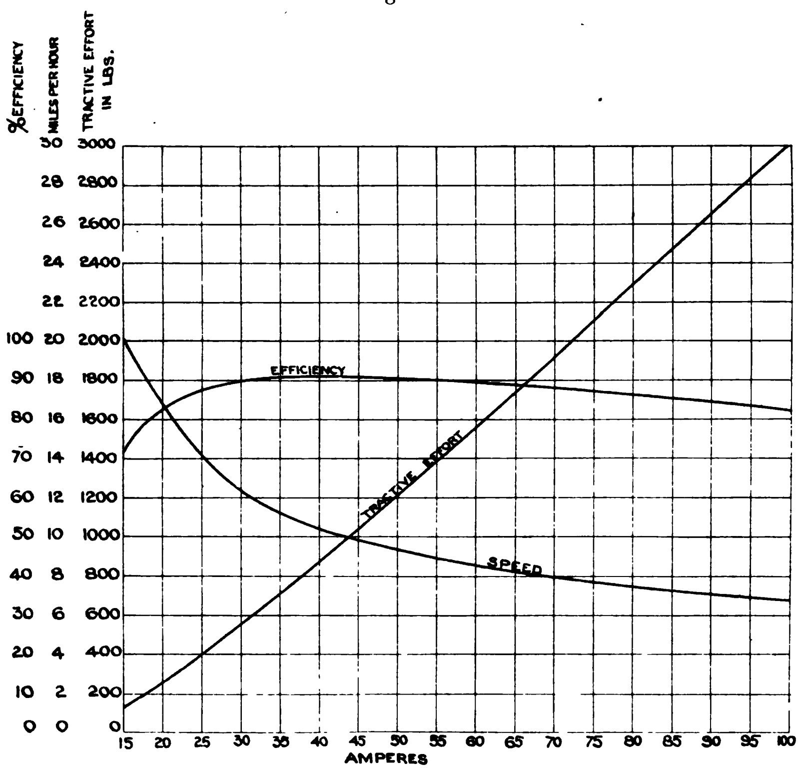
It was stated, in Chap. I., that the torque developed by any motor was independent of the speed, and this is perfectly true provided the current is unaltered. But, as the current taken by a traction motor depends upon the speed at which it runs, so the torque will vary exactly as the current varies, *i.e.* nearly in the inverse ratio to the speed.

Since the draw-bar pull is proportional to the torque, multiplied by the ratio of the gearing, we may increase the draw-bar pull by using a higher gearing, but the speed

* The effect of the regulating resistances of the controller being neglected.

of the car will be reduced. It is not possible, by altering the gearing, to increase the output of the motor in any way, unless, by so doing, the speed of the motor is itself increased.

Fig. 52.



CURVES OF DICK KERR MOTOR.

Motor Curves.—As an example of the various relations between speed, current, draw-bar pull, and efficiency of a traction motor, Fig. 52 is given. The values have

been obtained from a Dick Kerr motor, and are full of information.

These curves are the usual ones given by the motor manufacturers, but it is often more convenient to show the variations of the draw-bar pull with the speed, such as is done in Fig. 61, Chap. VI. With this curve the speed of the motor, for any required draw-bar pull, is given at a glance. If a speed of, say, 12 miles per hour is required, the motor must have work to do equal to a draw-bar pull of 330 lbs. If the condition of the track requires a greater draw-bar pull than this, a speed of 12 miles per hour cannot be obtained with that motor. As the motor increases in speed, so the draw-bar pull, which it can carry, decreases, and this has a very important bearing on the use of series motors, when working in series with each other.

Motors in Series and Parallel.—Take the case of two identical series-wound motors, and suppose that they are coupled in series when starting a car. Each motor will take the same current, and they will give equal torque, or draw-bar pull. So long as the motors run at the same speed, so long will they be doing equal work, since we saw, in Chap. I., that the work done by the motor depends upon the torque multiplied by the speed. Now suppose that the driving-wheels, to which one of motors is geared, begin to slip. That motor will then be doing less work than the other, and it will at once speed up, thus reducing the current through both motors, and, with it, the draw-bar pull. If the slipping continue, the motor in question will still further speed up, until the current from the line is diminished so much, that the motor, which is doing the work, will be unable to drive the car, and the car will therefore stop.

This example is no doubt a very unlikely one, but it illustrates the principle, and it shows that the necessity may arise, in extreme cases, of employing a direct mechanical coupling of the driving-wheels, when series motors are used, either starting or working in series with each other.

With shunt-wound motors, which run at nearly constant speed with varying loads, the same disadvantages do not exist. But such motors are practically never used for traction work, both on account of the smaller torque obtained for the same current, and also because of the great risk of the shunt-circuit being broken by bad contact, either on the rails or the trolley.

If we couple two motors in series, the same current will pass through each, and they will give equal torque. The speed of a motor, however, depends upon the E.M.F. at its terminals, and so we cannot obtain above half-speed, since we have divided the line E.M.F. between the two motors.

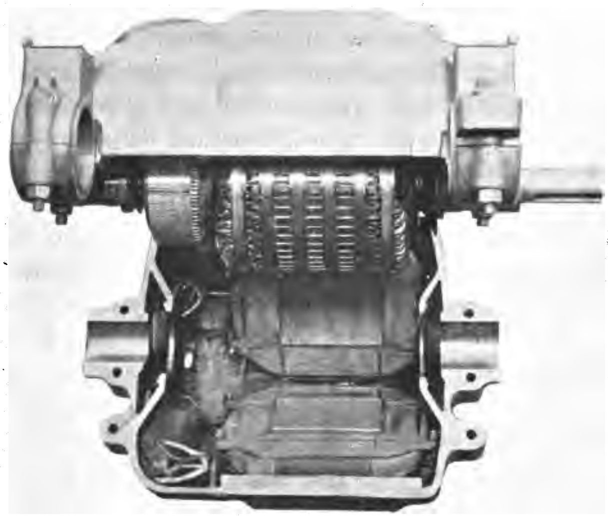
When the motors are connected in parallel, the same current as before must be passed through *each* motor if we wish to obtain the same torque, and therefore the current taken from the line will be doubled. But we obtain double the speed, since we have doubled the E.M.F.

Motor Construction.—We will now deal, somewhat in detail, with the construction of a modern motor. In too many cases motors are in charge of men who understand very little of the details of manufacture, and are therefore at a great loss when called upon to carry out anything except the most simple repairs. Hence the need for simplicity and uniformity.

Magnets.—The magnet shells of all traction motors are now made of mild cast steel, to secure low weight and

small dimensions. The shell is divided horizontally, the lower half being hinged to the upper half, as is shown in Fig. 53. Each half contains two pole pieces and two magnet coils. A large inspection hole is provided in the upper half of the magnet case, immediately over the

Fig. 53.



DIVIDED MAGNET SHELL OF MOTOR.

commutator, in order to give access to the brushes. This opening is covered with a strong iron lid, held in place by a spring. In large sizes, a door is often provided in the lower half of the shell, in addition.

The magnet casting must be of very high permeability, so that a strong magnetic field may be produced, with as

small an exciting current as possible. Much ingenuity is required by the steel-founders, to mould and cast successfully the very complicated shapes some makers adopt for the magnet shells, and that such excellent castings can be obtained speaks well for the ability of the founders.

The magnet poles project radially inwards, and are nearly always made of laminated steel, very similar to those in large generators. The laminations are necessary, in order to avoid eddy currents, which would otherwise be caused by variations in magnetic flux due to the armature slots. The complete pole is usually bolted to the magnet shell by two steel bolts, having counter-sunk heads let into the pole piece, below the curvature of the polar face. Some firms cast the magnet shell around the poles, and do not therefore use securing bolts. Both methods have their advantages, but the use of bolts would appear to be the better method. When the poles are bolted to the shell, they can be made with extended pole-tips, which are very useful for securing the magnet coils in place.

To assist in obtaining good commutation, a very strong magnetic field is used, and the magnetic density sometimes reaches very high figures, thus reducing the effect of armature reaction. The magnetic circuit, being a very good one on account of the small air-space, requires only a moderate magnetizing force, and so the field coils are comparatively small. The fact, that series coils are used, helps to keep down their size, since, with the large wire necessary, only a small space is wasted in insulation. In larger motors, copper strip is sometimes used instead of wire.

After the coils are wound, they are baked at a moderate temperature, until the moisture is driven out. They are then dipped into insulating varnish, similar to that used

for generator magnet coils, and are taped all over, as an additional protection.

The connections from the field coils are brought out, through the magnet shell, in the form of flexible cables,

Fig. 54.

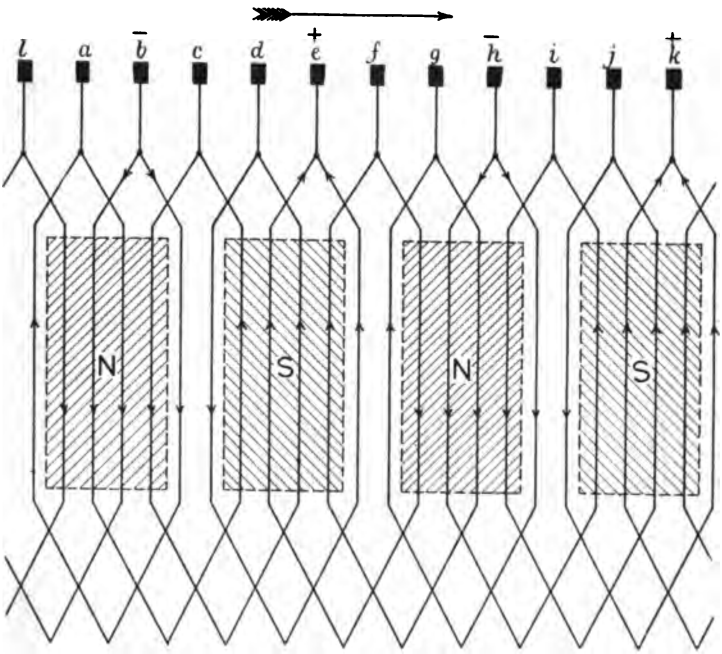


DIAGRAM OF PARALLEL ARMATURE WINDING.

hard wooden bushes being used where they pass through the shell itself. As it is necessary to connect up the fields and armatures of traction motors in several ways, the ends of the windings are always brought separately out of the case, to be taken direct to the controller.

Armatures.—As in modern traction generators, so also in motors, the armatures are always drum-wound, with multiple coils laid in slots. In order to have as small a self-induction as possible, the slots are usually made

Fig. 55.

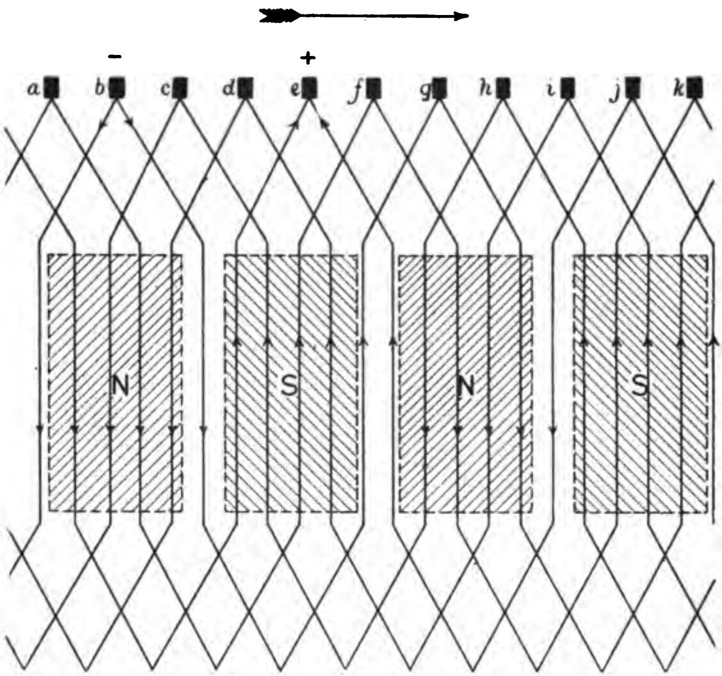


DIAGRAM OF SERIES ARMATURE WINDING.

wide enough to take several separate coils, with a very considerable saving in the amount of insulation required, as only a light insulation is necessary between adjacent coils.

There are several different methods of winding motor

armatures, but, as a rule, what is called a "series" winding is adopted, in order that only two collecting brushes need be used, and those 90° apart, and in a position where they are accessible on lifting the door at the top of the magnet case.

Figs. 54 and 55 will make clear the difference between parallel winding and series winding, on an armature intended for use in a 4-pole field. In the figures the windings are supposed to be laid out flat, and it will be seen that, in the parallel winding, the coils between one commutator section and the next are under the influence of only two poles at one time, whereas, in the series winding, they are under all four poles. Twice the E.M.F. and one-half the current are obtained in the latter case; and the brushes are only 90° apart. Series winding on armatures is sometimes called "wave" winding, from the wave-like form of the coil in plan.

One peculiarity about series-wound armatures is that an odd number of commutator sections is necessary, and therefore an odd number of slots and coils. A common arrangement is to have 41 slots in the core, each slot having three coils. There would therefore be 123 commutator sections. With a double, or quadruple, coil, and with either an even or an odd number of slots, we obtain an even number of commutator sections, and an arrangement which cannot be wound. The difficulty is removed, however, by making one of the coils a dummy, cutting off the ends and using it merely as a filling, and to give mechanical balance. A more common way is to wind with triple coils, and to use an odd number of slots.

It is very necessary that motor shafts should be exceedingly stiff, and well made of best mild steel, as they have to stand very heavy strains. The core-plates are threaded

on the shaft over a key, and are held in place by strong end-plates screwed on the shaft. Ventilating spaces are often provided, through the body of the core, by punching out openings in the plates, parallel to the shaft. This is possible, since the full depth of the core is seldom required for the magnetic lines. The discs are also separated into sections, by ventilating spaces communicating with the central holes already mentioned. In large armatures these ventilating spaces are very necessary, in order to keep down the temperature of the core.

The armature coils are wound on special formers, the three coils, which go into one slot, being taped up together. The shape of the coils varies almost with every maker, but, whatever form is used, it is very essential that the exact shape be given to the coil before it is laid in the armature slots. Any bending or adjusting, once the coil is formed, is always liable to damage the insulation. In large motors, of 100 H.P. and upwards, the winding takes the form of rectangular bars, having one turn per section, with four or five sections and two bars deep per slot.

After winding, the armature coils are dried, and the whole is served with a special insulating varnish, which must not only have waterproof properties, but must also be capable of standing fairly high temperatures, without becoming brittle.

The ends of the coils, which come out to the commutator, are given extra insulation, in the shape of additional braiding, or by taping with fine tape. The ends are placed in slots cut in the commutator bars, and are thoroughly sweated. Particulars of the commutator construction are given below.

When the armature is wound, and connected to the commutator, it must be carefully bound with bands

made of strong steel wire, placed about 3 in. apart, one band being also placed over each of the end windings. To prevent the bands coming off, the ends should be secured by small clips of copper strip, soldered in place. After the commutator has been turned up, the complete armature should be balanced on knife edges, and weighted so as to insure that it is in running, as well as statical, balance.

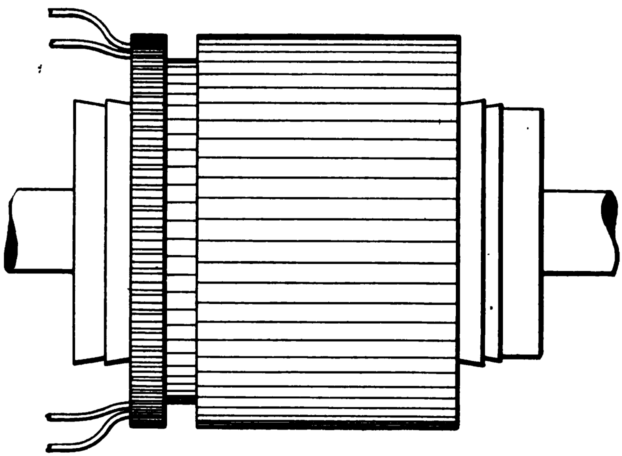
Commutators.—The commutator is a part of the motor which, perhaps, requires the greatest care in manufacture. It should be constructed of very tough copper, either hard-drawn, or drop-forged. Each sector should have plenty of radial depth, so as to allow for a deal of wear, and should be separated from adjacent ones by mica sheets, not less than ·035 in. thick. The mica requires careful selection, and it must not be too hard or too soft, as it should wear at the same rate as the copper segments. After the segments are assembled and clamped together, a groove is turned near the back end, in order to give clearance for the milling or slotting tool, when machining the grooves for the ends of the armature wires. This is shown in Fig. 56, and is a much superior type to that in which the segments have lugs. Commutators, made as described, are usually of larger diameter than those with lugs, in order that the segments may be brought nearer the connecting wires from the armature.

Clamping rings, with moulded micanite insulation, are used for holding the commutator in place. The rings are made in several forms, but the one shown in Fig. 56 is perhaps the best, as the sections are held against both inward and outward pressure. The whole commutator is generally baked at a high temperature, before the recesses for the clamping rings are turned out, and, when

the whole is finally clamped up on the shaft, it forms a thoroughly solid mechanical job.

It is very essential that the iron hub, which carries the commutator on the shaft, should be a good fit, to prevent the commutator from shifting about, and probably breaking the armature connections. The final truing of the commutator should not be done until after the first trial

Fig. 56.



MOTOR COMMUTATOR, WITH CLEARANCE GROOVE.

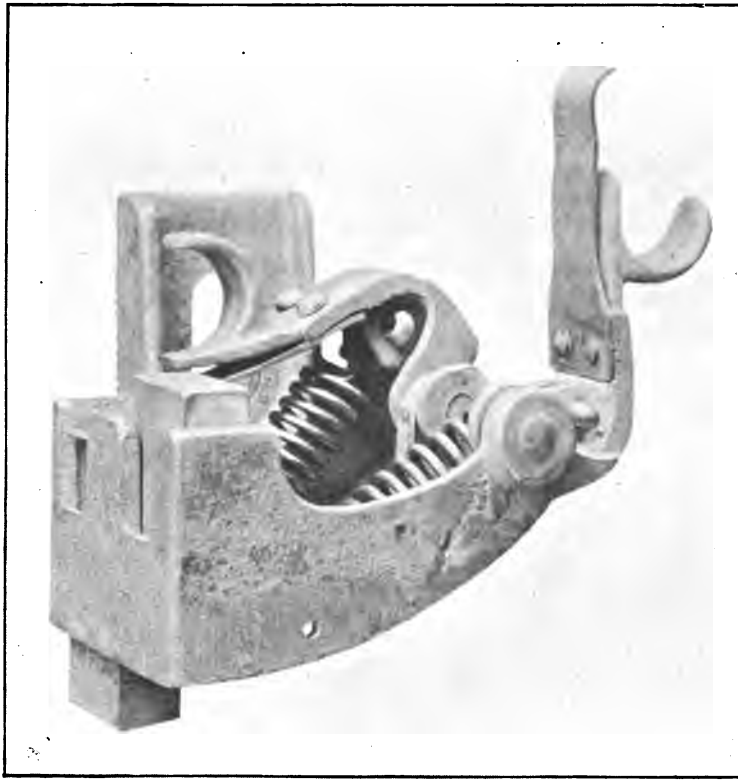
runs in the shop, and until the whole armature has been heated up, and the various parts have settled in their place.

The insulation of the complete armature and commutator should be capable of standing an alternating pressure of 2,000 volts for 15 minutes, and, while hot after a run, should have an insulation resistance of between 5 and 10 megohms.

Brushes.—The brushes for traction motors are now

always made of carbon blocks, usually measuring $2\frac{1}{4}$ in. $\times$ $2\frac{1}{4}$ in. $\times$ $\frac{5}{8}$ in. They must press radially on the commutator,

Fig. 57.



MOTOR BRUSH GEAR.

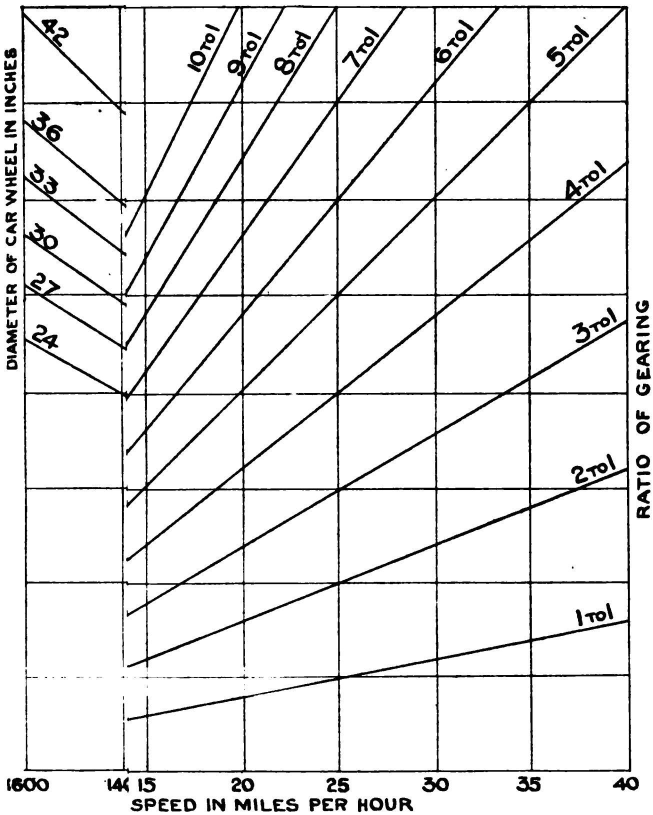
since the armature is required to run equally well in either direction. The brush holder generally takes the form of a brass box, containing one or more brushes which can

slide freely in or out. The brushes are held on to the commutator by a strong swinging arm, backed up with a good spring. The brush holders themselves are usually fixed to a hard wood base, which has been treated with boiled paraffin wax, and screwed to the upper half of the magnet case.

As the brush gear is subjected to very considerable vibration, it is essential that all parts should be very strong and rigid, with nuts secured by means of lock-nuts and split pins. There is no part of a traction motor more likely to give trouble, if badly designed and made, than the brush gear, and the probable destruction of the commutator may be the result. In Fig. 57 is shown a good form of brush gear, from which the main features will be understood.

Gearing.—Motors for tramcars often have to run at a speed of about 1,000 revolutions per minute, and the armature shaft is geared to the axle of the car by what is known as single reduction gearing, *i.e.* the speed is reduced once, by means of a pinion on the motor shaft, and a spur-wheel on the car axle. In the early days, double reduction gearing was sometimes used, and even motors with no gearing at all, the armature being mounted directly upon the car axle. But the former was found inefficient, noisy, and expensive to maintain, while the latter meant a motor of a much larger size. In addition, it was impossible to keep the vibration, caused by an irregular road-bed, from the armature, and, although direct-mounted motors are still occasionally used in railway work, single reduction gearing has become universal for tramcars.

The ratio of the gear is usually of the order of 4 or 5 to 1, a motor speed, of 1,000 revolutions per minute,



To face page 148.

therefore meaning a car axle speed of from 200 to 250 revolutions per minute. The motor pinion should always be made of well-hammered steel, with a taper bore fitting tightly on the tapered end of the armature shaft. The taper, if properly made, insures a good fit, and the pinion is secured by a key and an external lock-nut.

The spur-wheel, on the car axle, is generally made of cast steel, and is in two halves bolted together. Both the pinion and the spur-wheel are machine cut, with involute teeth, usually about 3 pitch for motors up to 50 H.P., 2½ pitch up to 100 H.P., and, where possible, 2 pitch for larger sizes. The pinion often has 14 teeth, and the spur-wheel 68 teeth, and it is very essential, for smooth and efficient working, that the fitting of the gear should be of the highest class.

Gear cases, made of cast-iron, are always employed, to protect the gear from dirt, and also in order to hold a supply of lubricating grease. A small opening is usually provided at the top of the gear case, through which the lubrication can be applied.

In Fig. 58 is given a diagram, which shows the speed of a car with different diameters of wheels, gear ratios, and armature speeds. It will be found very useful in making rapid calculations, as it can be used in several ways.

Bearings.—The motor armature shaft runs in bearings, which are either of gun metal or white metal, in malleable cast-iron shells. Gun metal is probably the best to use, since it is tougher and will wear longer. It also has the advantage that it will not melt if the bearing heat through lack of lubrication. Cases have been known where, owing to the melting of the white metal, the armature shaft has

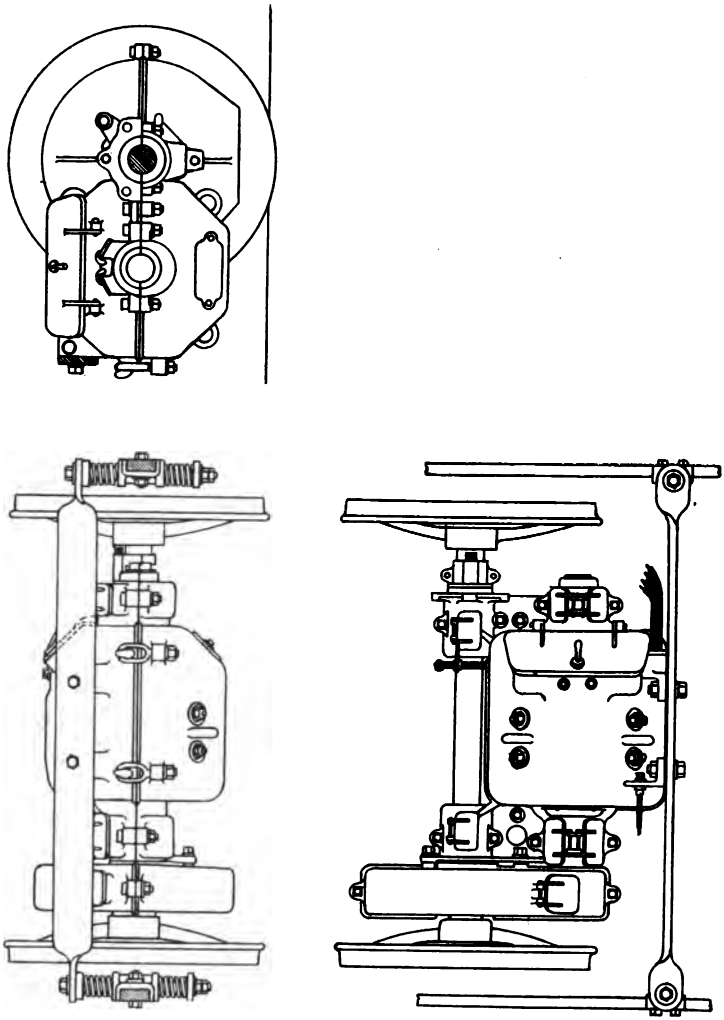
dropped in place, thus bringing the armature in contact with the pole pieces, stripping the binding wires off, and generally spoiling the armature.

Lubrication.—The methods of lubrication, in common use for tramcar motors, leave much to be desired. The plan usually adopted is to employ felt pads, which dip into the oil reservoir, and are held up to the shaft by springs. Solid grease lubricators are often fitted, in addition, but they are not of much use until the bearings begin to heat. Considering the conditions under which a traction motor has to run, it is very surprising that more attention is not paid to this question. Stationary motors, which can have constant attention, have elaborate systems of lubrication, such as oil-rings, and even force-pumps, but the traction motor, which has to run under all kinds of conditions and without attention, has, so far, to be content with such crude methods as those indicated above.

One reason, why more copious lubrication is not provided, is probably because of the difficulty of keeping surplus oil out of the motor case. But it should be quite possible to design oil throwers and catchers suitable for this purpose. Should the oil get inside the motor, it would very quickly damage the insulation of the magnet coils, since no amount of treating will render them entirely impervious to oil. The hand hole, on the lower half of the motor case, should be frequently used, in order to remove any oil which may get inside.

Motor Suspensions.—There are two principal methods of suspending the motor on the truck, the first being known as nose suspension, and the second as side-bar suspension. The former is illustrated in Fig. 59. One side of the motor case rests upon the car axle, through the medium of special

Fig. 59.



NOSE SUSPENSION.

bearings, while a projecting lug on the other side rests upon a steel cross-bar, which is carried by two strong springs on the side frames of the truck.

In the side-bar method of suspension, which is shown in Fig. 60, two parallel bars are employed, fixed to opposite sides of the motor case at right-angles to the shaft, and carried by a frame resting on the truck. Nose suspension has proved the more satisfactory in actual use, and is generally adopted.

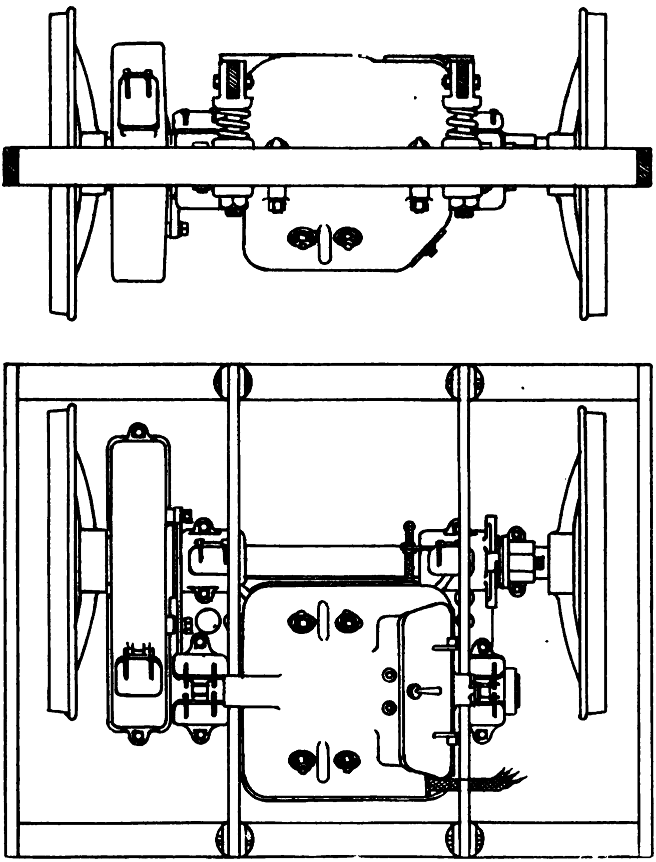
The question of a suitable suspension is a very important one, since the life of the motor will depend largely upon its freedom from jolting, when running over the road. If a perfect road-bed could be maintained, then the method of suspension would not be so important, but in every-day practice it is not possible to ensure this.

Motors for High Powers.—When high-power motors are required on narrow gauge roads, it is often a most difficult matter to design a reliable machine to fit in the very confined space available. In such cases various modifications of the standard types have to be made. The usual practice is to increase the diameter of the armature core and to reduce its comparative length. The ends of the coils, farthest from the commutator, are carried on a cylindrical sleeve, into the interior of which the greater part of the bearing projects. The commutator is also increased in diameter, and is arranged with a hollow centre, into which the bearing projects. In this way the overall length of the motor is brought down to the smallest possible amount. Each particular case generally means a special design.

Motor Inspection.—One of the most important points in the working of any electric traction system is that of frequent inspection of the motors. Nowhere is the truth of the old adage, "a stitch in time saves nine," more

exemplified than with motor equipments. Many a break-down on the road can be avoided by systematic inspection

Fig. 60.



SIDE-BAR SUSPENSION.

and examination, and by the observance of strict cleanliness, particularly with the commutators and brushes.

With proper care motors should run for several years, before the commutators require re-turning, and several months before the brushes require renewing. Such a simple thing as the application of a very little vaseline to the commutators, by means of a soft pad at the end of a stick, as each car is leaving the shed in the morning, will be found to have a very beneficial effect in reducing, not only the wear, but also the objectionable humming noise caused by dry carbon brushes.

CHAPTER VI.

CONTROLLERS.

Functions of Controller—Starting a Car, with one Motor—Starting a Car, with two Motors—Advantages of series-parallel Control—Four Motor Controllers—Example of Control on C.L.R.—Brake Controller—Effect of braking on Motors—Position of Controller—Arrangement of Controller—Motor combinations—Details of Car Controller—Multiple-unit Systems—The Sprague System—Advantages and disadvantages of Multiple-unit Systems—The Westinghouse System—The General Electric System.

Functions of Controller.—Next only in importance to the motors themselves, is the apparatus by which they are controlled. The modern controller is essentially an evolution. To start, or to stop, a motor, a simple switch only is necessary, but, for traction work, in addition to this, we must have some means of regulating the speed, and of reversing the motion.

Originally tramcars were fitted with but one motor, and the controller was required only to switch the current on and off, through a series of resistance steps, and to change the connections for reversing. When two motors became necessary, it was clearly seen that a simple resistance control was insufficient. The speed of a motor, under given conditions of load, is practically proportional to the E.M.F. at its terminals, while the torque, as we have seen in Chap. I., is proportional to the current only, and is independent of the speed. The greatest torque is required

during the starting and acceleration of a car, and, therefore, at a time when there is little or no back E.M.F. If the two motors be connected in parallel, we shall require twice the current to produce a given torque with each motor, than if we connected the two motors in series, and allowed the same current to flow through both. In order, then, to economize in current, it is desirable that the motors be connected in series, when *starting* the car. If, however, we keep them in series, we are only able to give each motor one half the total E.M.F., and, consequently, we cannot get above half speed, since the speed is practically proportional to the E.M.F. We shall, therefore, require some means of connecting the two motors in parallel, when half speed is reached, to give each motor the full E.M.F., and so to run the car at its full speed. Briefly stated, the functions of a modern controller are—

(*a*) To connect both motors in series, with the whole of the regulating resistance.

(*b*) To cut out the resistance in steps, until both motors are in series with no resistance.

(*c*) To connect both motors in parallel, with part of the resistance in series with them.

(*d*) To cut out the resistance in steps, until the motors are in parallel, with no resistance.

(*e*) To reverse the field magnet connections, so that the motors will run in the reverse direction.

(*f*) To couple the motors so that they will work in parallel as dynamos, thus acting as brakes.

A controller thus practically resolves itself into a complicated arrangement of switches, compressed into a small compass, and capable of being worked, under all kinds of conditions, by comparatively unskilled labour.

Before describing the construction of the controller, we

will consider, in detail, the various reactions which take place in starting up a car.

Starting a Car, with one Motor.—First, take the case of one series motor, with a simple starting resistance, for example, the motor of which particulars are given in Table 4. Assume the car has a retardation of 580 lbs., due to tractive resistance. Suppose the first contact of the starting resistance allows 45 ampères to flow through the motor. It will be seen from the table that the corresponding draw-bar pull is 1,200 lbs. This will give 580 lbs. to overcome tractive resistance, and 620 lbs. will be available for acceleration.

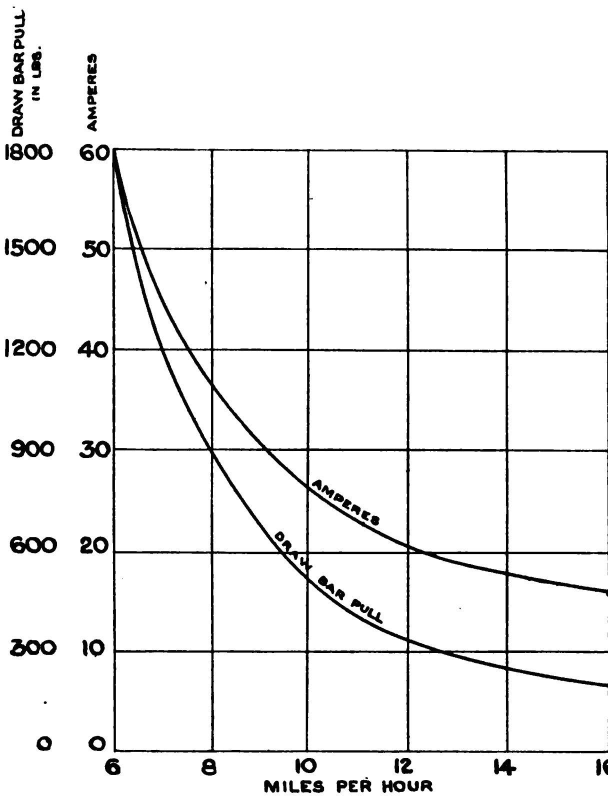
TABLE 4.—NO. 46 WESTINGHOUSE MOTOR, GEAR RATIO 1 TO 4·14, CAR WHEELS 30 IN. DIAMETER.

Miles per hour.	Ampères.	Draw-bar pull.
6	60	1800
6·5	52	1475
7	45	1200
8	36·5	900
10	26	500
12	20·6	330
14	18	240
16	16	198

The motor will at once start up, generating a back E.M.F., thus causing the current to fall. If, however, the starting resistance be switched out, at a rate corresponding with the acceleration of the speed of the car, a balance can be maintained between the rising back E.M.F., and the diminishing starting resistance, so that the current through the motor is maintained constant, until the resistance is entirely cut out. In the present example, this will be when a speed of 7 miles per hour is reached.

The increasing speed, and the rising back E.M.F., will then cause the current to fall, until it reaches that definite

Fig. 61.



CURVES OF NO. 46 WESTINGHOUSE MOTOR.

value, which is required to give a draw-bar pull, equal to the retardation of 580 lbs. In this particular case the current is 28 ampères, with a corresponding speed of 9·4

miles per hour. If the tractive resistance, and, consequently, the retardation, could be diminished, the car would further speed up, until the speed and current again agreed with the new value of the retardation. So long as the current is kept constant, by cutting out resistance, the accelerating pull is also constant (if the retardation be constant), and, as the current falls, the accelerating pull falls with it. The effect on the car is a uniform acceleration, so long as the resistance is being cut out, and then a gradual decrease in the acceleration, until uniform speed is obtained.

Knowing the draw-bar pull corresponding to various speeds, the current to give these values of draw-bar pull can be tabulated from the motor curve in Fig. 61. The energy represented by this current is used—

(1) In the regulating resistance.

(2) In accelerating the car.

(3) In overcoming the track and gravity retardation.

Starting a Car, with two Motors.—Next take the case of two series motors of equal power, and a car double the weight of the preceding one. The motors can be used either in series or in parallel. When in series, the same current from the line passes through both, and the draw-bar pull, due to a current of 45 ampères through the motors in series, is the same as that due to a line current of 90 ampères, when the motors are in parallel. The motors, in series, will speed up together, at the same rate, being practically mechanically coupled (if there be no slip of the wheels on the track), and, if the starting resistance be cut out at the proper rate, the current through the series combination can be kept constant, until the speed of the car has reached 3·5 miles per hour, or half the previous value. If the two motors still continue in series, the current would fall as the speed rises, until a speed of

4·7 miles per hour is reached, which is the limiting speed when the motors are required to furnish a draw-bar pull of 580 lbs. each. The two speeds just given, of 3·5 and 4·7 miles per hour, are half the corresponding values of those attained, either with the single motor, or when the motors are in parallel.

TABLE 5.—PARTICULARS OF SERIES-PARALLEL CONTROL, WITH TWO No. 46 WESTINGHOUSE MOTORS, ON 12-TON CAR.

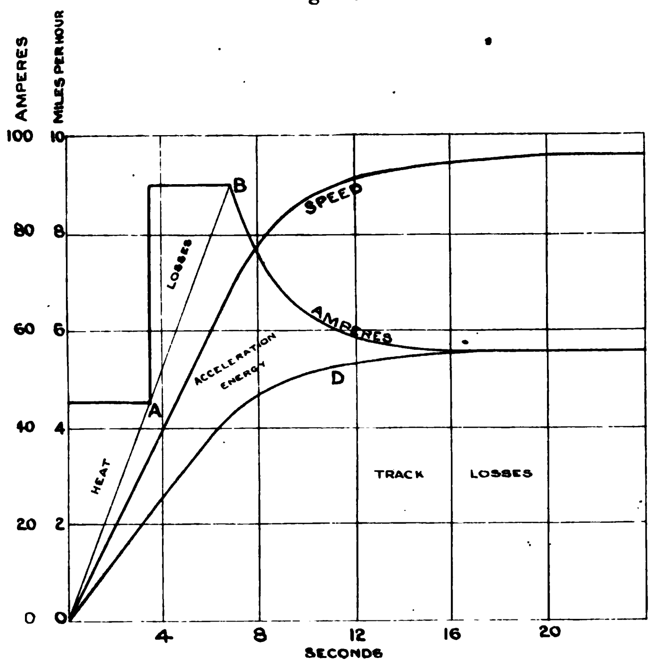
Miles per hour.	Ampères per Motor.	Ampères Total.	Per Motor. D.B.P.	Per Motor. Retardation.	Per Motor. Accelerating pull.	Accelerating pull per ton load.	Acceleration in Miles per hour per second.	Ampères for Track losses.	Remarks.
0–3·5	45	45	1200	580	620	103	1·0	22	Motors in Series.
3·5–7	45	90	1200	580	620	103	1·0	43·5	Motors in parallel, with resistance.
7·2	42·5	85	1140	580	560	93	·91	43·5	All resistance out.
7·6	40	80	1020	580	440	73	·717	45·5	
8	36·5	73	890	580	310	52	·573	47·5	Current and draw-bar pull decreasing, as speed becomes nearly constant.
8·4	33·5	67	780	580	200	33	·33	49·7	
8·8	31·5	63	700	580	120	20	·195	52	
9·2	29	58	620	580	40	7	·07	54·5	
9·4	28	56	580	580	0	0	·0	56	

When the two motors, in series, have brought the car speed to 3·5 miles per hour, and all the resistance is cut out, suppose the motors to be switched into parallel, with sufficient starting resistance to limit the current to 90 ampères, or 45 ampères per motor. The draw-bar pull will remain at 1,200 lbs. per motor, and the motors can speed up to 7 miles per hour, until all the resistance is again cut out. When this point is reached, the motors will further speed up, with constantly diminishing current and draw-bar pull, until a speed of 9·4 miles per hour is reached, with a draw-bar pull of 580 lbs. per motor. These results are given in Table 5.

Advantages of series-parallel Control.—The advantages of the series-parallel control are, the double torque obtained

at starting, for the same current, and the higher speed with the parallel connection afterwards. The arrangement is analogous to a mechanical gearing, with a ratio of 1 to 2, which is thrown into a ratio of 1 to 1, when the motors are connected in parallel.

Fig. 62.



SERIES-PARALLEL CURVES. CORRECT SWITCHING.

In Fig. 62 the various values, given in the above table, have been plotted out, and the current curve shows a sudden rise to 45 ampères, when the motors are first switched on, and a further rise to 90 ampères, when they are connected in parallel.

The area, enclosed by the current curve and the horizontal, represents the energy, since it is proportional to the current at a constant pressure (in this case) of 500 volts.

At the two points, *A* and *B*, all the starting resistance is cut out, and no energy is lost in the resistance coils. The triangular areas, enclosed between the current curve and the two straight lines joining *OA* and *AB*, represent the losses in the starting resistances.

Having plotted the current used in track retardation, shown in curve D, we now have a complete record, showing how the power supplied by the line is utilized. Starting from zero, the current is largely used to overcome track retardation, and, at about equal rates, in the accelerating and resistance losses. The latter cease at *A*, as at that point all the resistance has been cut out.

When the motors are switched into parallel, the resistance is again inserted, and the losses due to it are again shown, ceasing at *B*. As the car increases in speed, the current falls, but the amount used to overcome the track retardation increases, until it coincides with the total current, and then no energy is available for further acceleration.

The rectangular area, between the vertical axis from 45 to 90 and the current curve, represents the energy which is saved by using a series-parallel arrangement. If the motors had been started directly in parallel, the current would have risen at once to 90 ampères, in order to give the same speed, and the triangular area, between the vertical axis and *B*, would represent resistance losses.

In the example we are considering, the actual amount of energy, thus saved, is 45 ampères × 500 volts × 3·5 seconds = 78,700 watt-seconds. The ratio of watt-seconds

to foot-pounds being as 746 is to 550, the energy saved is $78{,}700 \times \frac{550}{746} = 58{,}000$ foot-pounds.

In plotting these various curves, the following assumptions have been made, viz.—

(1) That the controller has sufficient resistance steps, and is handled at such a rate, as to keep the current constant.
(2) That the variations of the current are not so rapid as to be influenced by the self-induction of the motors.
(3) That the motors are changed from series to parallel connection, immediately they have attained the correct series speed, with all resistance cut out.

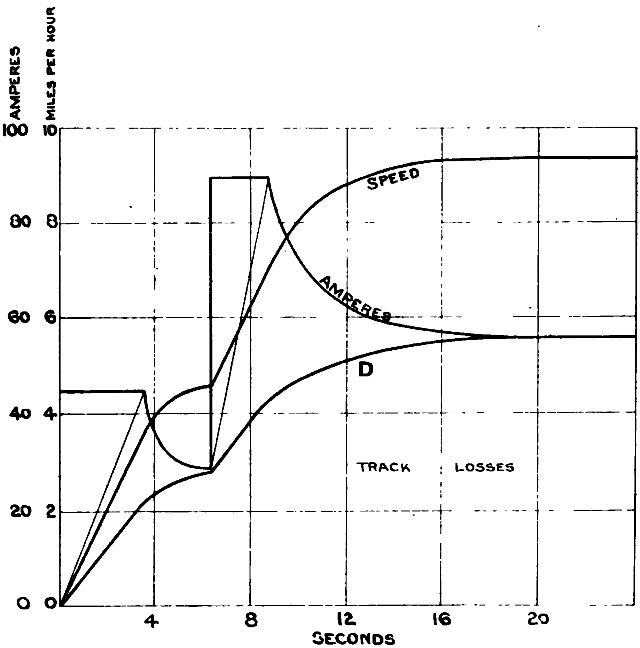
The first two conditions must be allowed, or the problem becomes too complicated for solution. The effect of the third condition we will briefly examine.

If the motors be changed from series to parallel connection, *before* reaching the correct speed, the effect is simply to double the current earlier, without any change in the accelerating curve, the draw-bar pull being the same, namely, 1,200 lbs. per motor, for the current of 45 ampères per motor, in either case. If, however, the change from series to parallel be delayed, the motors will continue to speed up, with increasing back E.M.F., and with no further starting resistance to cut out. Consequently the current will fall, and, with it, the draw-bar pull, and the accelerating pull. The speed curve will bend over, until a constant speed of 4·7 miles per hour is reached, or until the motors are put into parallel.

When this is done, the speed curve will again become straight, and at the same inclination as before, and an uncomfortable jerk of the car will be felt.

The speed curve, in Fig. 63, has been drawn out for such a case, on the assumption that the motors were

Fig. 63.



SERIES-PARALLEL CURVES. LATE SWITCHING.

switched into parallel 5·2 seconds after starting, instead of 3·5 seconds, as in Fig. 62. It will be seen that the curve changes sharply in character, between those times, and becomes straight again, when the parallel connection takes place.

To switch into parallel before the motors have reached their full speed, in their series position, wastes considerable energy, without any gain, or loss, to either the speed or acceleration. To switch into parallel some time after the motors have reached their full speed, in the series connection, wastes no energy, but reduces the acceleration, and increases the time required to attain full speed.

It may be remarked here, that some type of controllers are arranged with shunt resistances, in order to weaken the fields of the motors, after they have reached their full speed, in the ordinary parallel combination. The effect of this is to increase the speed still further, but such an arrangement is only useful, when a high rate of speed is required on a level road, since diminution of the field strength reduces the torque of the motors, as was shown in Chap. I., and, in consequence, the draw-bar pull is reduced likewise.

Four Motor Controllers.—In some cases, as, for example, in railway equipments, 4 motors per car are used instead of 2, and then the combination of series and parallel connections can be carried still further. Thus we may have—

(1) All 4 motors in series.

(2) Two motors in series and 2 in parallel.

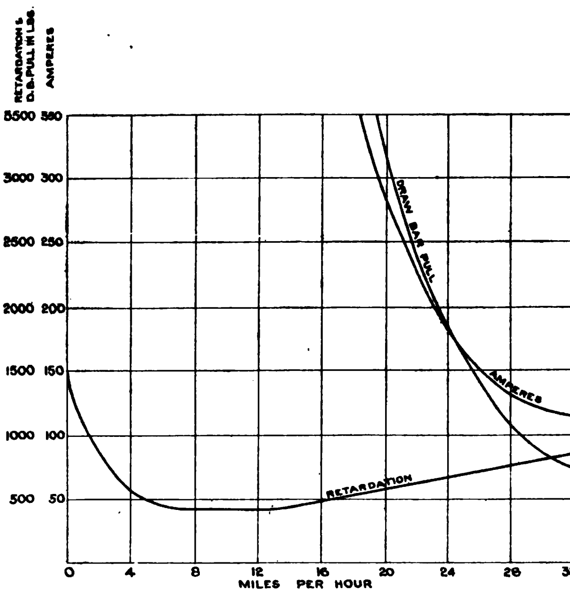
(3) All 4 motors in parallel.

In order to obtain the same draw-bar pull throughout, the line current, in the 3 combinations given, must increase in the ratio of 1, 2, and 4, the current per motor being the same in each case.

Example of Control on C. L. R.—As a further example in motor control, we will take the case of the Central London Railway, particulars of the motors being given in the *Electrician*, April 12, 1901. In Fig. 64, the curve showing

the relation of draw-bar pull to speed, the curve of current and speed, and the retardation curve, have been drawn. The retardation has not been taken as being constant, as in the previous case of the tramcar, but has been made to vary with the speed, in the relation shown to hold for high speeds and rails without grooves.*

Fig. 64.



C.L.R. MOTOR CURVES.

Thus, at starting the tractive effort is 40 lbs. per ton, at a speed of from 6 to 13 miles per hour it is 10 lbs. per ton, and at a speed of from 13 to 35 miles per hour, the tractive effort increases, being 21 lbs. per ton at a speed of

* McMahon, *Jnl. Inst. Elec. Eng.*, No. 141, p. 592.

26 miles per hour. The total retardation, for the various speeds, given in Table 6, has been calculated for a train load of 148 tons, and has been divided by 4 to give the retardation per motor. From the results the curves in Fig. 64 have been plotted.

The two curves, of draw-bar pull and retardation, cross at a speed of 30·6 miles per hour, which is the point at which acceleration vanishes, and is the constant running speed under the conditions named.

Assuming that the controlling resistances allow of 300 ampères per motor throughout, and that constant acceleration is maintained, *i.e.* that the motors are switched into parallel at the right time, the following values are obtained from the curves, viz.—

TABLE 6.—PARTICULARS OF SERIES-PARALLEL CONTROL ON C. L. RAILWAY.

Miles per hour.	Ampères per Motor.	Ampères Total.	Per Motor. D.B.P.	Per Motor. Retardation.	Per Motor. Accelerating pull.	Ampères used in Accelerating.	Ampères used in Track losses.	Acceleration in Miles per hour per second.	Remarks.
0	300	300	3450	1480	1970			·51	4 Motors in series with resistance, which is gradually cut out.
1	300	300	3450	1100	2350			·61	
2	300	300	3450	860	2590			·73	
4	300	300	3450	560	2890			·76	
4·9	300	300	3450	500	2950	256·5	43·5	·78	All resistance out.
4·9	300	600	3450	500	2950			·78	2 Motors series and 2 parallel with resistance.
6	300	600	3450	420	3030			·8	
9·75	300	600	3450	420	3030	527	73	·8	All resistance out.
9·75	300	1200	3450	420	3030			·8	4 Motors parallel with resistance, which is gradually cut out.
13	300	1200	3450	420	3030			·8	
15	300	1200	3450	460	2990			·78	
19·5	300	1200	3450	570	2880	1000	200	·76	All resistance out.
21	260	1040	2720	600	2120	810	230	·58	Current and draw-bar pull decreasing, as speed becomes nearly constant.
23	200	800	2100	650	1450	550	250	·485	
25	165	660	1600	700	900	365	295	·235	
26	150	600	1400	720	680	290	310	·178	
27	140	560	1180	740	440	210	350	·115	
28	130	520	1090	750	340	160	360	·09	
29	125	500	970	780	190	100	400	·05	
30	120	480	860	800	60	30	450	·0165	
30·6	117	468	820	820	0	0	468	0	Constant speed.

The highest acceleration recorded, namely, 0·8 miles per

then the saving would be limited to that shown by the second of the two areas just mentioned, namely, 2,970,000 foot-pounds.

In order to avoid complication of contacts on controllers, when four motors are used, the steps are usually limited to two, with a corresponding small loss of energy each time the train is started.

The tendency, in equipping modern electric railways, is to provide for very rapid acceleration, the General Electric Co. of Schenectady maintaining that an acceleration of 4·3 ft. per second per second is possible. The usual value at present, with electric traction, is about 2·5 ft. per second per second, while with steam traction about ·45 ft. per second per second has been the highest reached.

Brake Controller.—In addition to the series and parallel positions, a number of modern controllers have a third, or brake, position. When the controller is in this position, the connections of the motor field coils are reversed, so that, when the motors are driven by the momentum of the car, they work as dynamos. In this combination the two motors are usually placed in parallel, with a variable external resistance across their terminals. The motors, being driven by the motion of the car, at once begin to do work, by sending a current through the external resistance, and therefore tend to stop the motion of the car.

The amount of brake action, which is obtained, can be varied by altering the value of the external resistance. It is more gradual and uniform than any type of wheel-brake, it can be applied with such force as to pull up the car in a very few yards, and there is no tendency to make the wheels skid, since the braking action depends upon the motion of the wheels for its existence. Such a brake will not, of course, hold a car upon an incline, as immedi-

ately the car is pulled up it would start again, to be again pulled up, and so on. While, therefore, the electric brake is exceedingly valuable, both in cases of emergency, and also for descending sharp gradients, yet an ordinary hand-brake must be used, to hold the car after it has been stopped.

There is always the likelihood of the motors failing to act as brakes, in the manner indicated above, unless care be taken to keep the commutators, controllers, and brushes clean, and in good condition. Otherwise the resistance of the circuit may be so high, that the motors will not excite, with the small amount of residual field usually found, and so no brake action will be obtained. If, however, ordinary care be taken, to keep the motors, controllers, and connections in proper order, this type of electric brake is one of the most reliable and powerful that can be wished.*

Effect of Braking on Motors.—If the motors be constantly used for braking, they will be found to reach a much higher temperature, than when used only for their ordinary work, since they will have no rest, even when the car is running down-hill, and allowance for this must be made in determining the size of the motors. If, however, the electric brake be not too frequently used, the extra heating is not likely to be serious.

Position of Controller.—Two controllers are necessary on every vehicle, which may have to be driven from either end, this being the usual case with tramcars. The controllers are identical in arrangement and connections, but, of course, only one is used at a time. To insure that this shall be done, the controller handles are made removable, and only one set is provided for each car. The mechanical arrangements of the controllers are such, that the handles

* See also page 202, Chap. VII.

cannot be removed, unless the controller contacts have been brought to the off position. Consequently it is certain, that, when one controller is in use, the other is cut off entirely.

The best position for the tramcar controller is on the platform, just inside the dashboard, and a little to the left of the centre line, so that the driver can stand, facing the direction in which the car is travelling, with his left hand on the controller handle, and his right hand on the brake handle. In some towns, on account of the particular design of the car platforms, or of the staircases to the roof, this position for the controller is not adopted, with the result that the driver has to stand in, what may be fairly termed, an unnatural position.

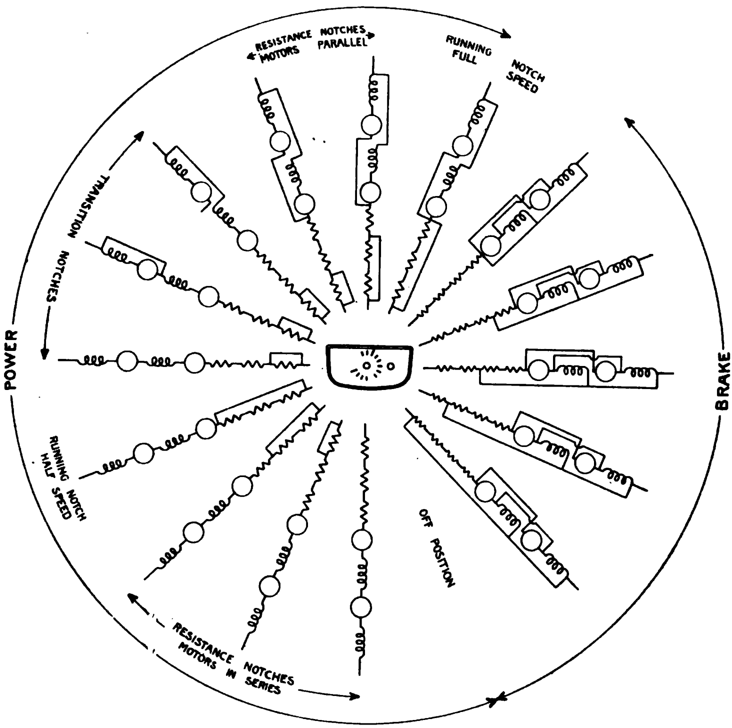
Arrangement of Controller.—The operations of the controller are governed by two handles, which, as mentioned above, are removable. The first, or reversing, handle is only a small one, and its use is merely for altering the connections of the motors, so that the car can be made to travel in either direction, when the current is switched on by the second handle.

The second handle is the one which is in constant use, for carrying out the various combinations of series and parallel control, which have been mentioned earlier in this chapter. The mechanical interlocking is such that the second handle cannot be moved, unless the first handle is either in the forward or reverse position, and so that, once the second handle is moved into a live position, the first handle can neither be removed nor changed.

Motor Combinations.—In Fig. 66 is given a diagram, showing the various controller handle positions, with the corresponding motor connections. Starting from the off position, it will be seen that the first contact switches the

two motors in series, with the whole of the regulating resistance. The second, third, and fourth contacts cut the resistance out in sections, and leave the motors in

Fig. 66.



CONTROLLER POSITIONS AND MOTOR CONNECTIONS.

series with no regulating resistance. This is the half-speed position, as was mentioned earlier. It will be noticed that there is a considerable gap between the last series position and the first parallel position. Between

these points various changes of the connections have to be made, in order to bring about the required combination. These changes are indicated in the figure, the first being to re-insert a portion of the regulating resistance, the second to short-circuit one of the motors, the third to connect one side of the short-circuited motor with the corresponding side of the other motor, and to break the connection on the other side of the short-circuited motor. The fourth change connects this side of the motor in parallel with the corresponding side of the other motor. These changes will be quite clear from the diagram, and the driver, or motorman, is instructed to move the controller handle very quickly over these transition points, and on no account to stop on either of them, since they are not running positions. When the motors have been brought into parallel, the regulating resistance is again cut out, by moving over the two following positions, until the motors are in parallel with no resistance.

To any one not accustomed to deal with series-wound motors, it may appear to be a most unwise proceeding to short-circuit one in the manner just mentioned. But a series motor is not a series dynamo. To short-circuit the latter would result in great damage, but to short-circuit a series motor does no harm whatever to the motor, since the action of short-circuiting deprives the motor of its field, and a series motor cannot generate any current, even on a short circuit, until its field coils are connected in the opposite way.

Details of Car Controller.—In Fig. 67 is illustrated a modern controller, with the front cover removed, so as to show the working parts. The main cylinder, which is worked by the controlling handle, carries a number of contact segments of varying lengths. A row of spring

contact fingers is fixed parallel to the cylinder, so that the

Fig. 67.

CAR CONTROLLER, WITH COVER REMOVED.

segments on the cylinder make contact with the fingers, as

the cylinder is revolved. The contact fingers are connected, by means of insulated wires, to the armatures and field coils of the motors, and to the various sections of the regulating resistances. The contact segments on the cylinder are connected to one another, in various ways, and it is possible, by rotating the cylinder, and so making various combinations in the connections between the contact fingers, to obtain such a variety of changes as is shown in Fig. 66, above.

In some types of controllers, an electro magnet, or a solenoid, is used, to blow out the spark, when the circuit is broken. In others, the circuit is broken at several contacts at once, so as to reduce the sparking at any one. Each method has its advocates, and both have given excellent results in practice.

To the right of the main cylinder, and controlled by the reversing handle, is the reversing cylinder. This cylinder is similar in its action to the main cylinder, but is only used to reverse the connections of the field coils of the motors, so that they will run in the opposite direction, when the current is switched on.

In addition to the cylinders and their multiple contacts, it is customary and convenient to fix, within each controller case, two switches by means of which either motor can be cut permanently off the circuit, in case of any failure. These switches can only be operated by opening the controller case. The best types of controllers are so arranged, that it is impossible to move the main cylinder beyond the series position, when either of the motors is cut out in this way. In Fig. 68 is shown a developed diagram of the connections on a car, including the two controllers, the two motors, the regulating resistances, and their various connections. It is practically impossible to describe a

modern controller, in such a way as to make its action quite clear to any one who is unfamiliar with its general construction. The only way to understand a controller thoroughly, and to appreciate the great skill and ability of those who have evolved it, is to examine one, to trace out its connections, and then to handle it in actual service.

Multiple-unit Systems.—The controller, briefly described above, is the type usually adopted for ordinary tramcar work, where each vehicle has its own driver. When, however, we have to deal with trains made up of a number of carriages, a frequent arrangement is to have each car equipped with its own motors and controllers, these controllers being all operated, from the front of the train, by a master controller. This method of control is known as the multiple-unit system, and it has been brought to a high degree of perfection, in the United States, by Mr. F. J. Sprague.

The relative merits of an electric locomotive in the front of the train, and separate motors on each car, are dealt with in Chap. XIV. We need only consider here the controlling devices necessary in either case.

When a locomotive is used, a controller on the same general principle as the one just described is used, with, of course, the necessary modifications due to the large powers and the increased number of motors with which it has to deal, and the confined space available for it in the cab of the locomotive.

When the multiple-unit system is used, all the motors must be operated together, from whichever end of any car or carriage happens to be in the front of the train. It is obvious, therefore, that a modification of the ordinary controller must be made.

The Sprague System.—In the system invented by Mr.

Sprague, each car is provided with a controller, which control the motors on that car only. The controller consists of two distinct parts—(1) a reversing cylinder for determining the direction of rotation of the motors; (2) a cylinder for putting the motors either into series or parallel connection with themselves, and for adjusting the regulating resistance.

The controllers on all the cars are operated together in the following manner. By means of a small master controller, fixed at either end of the train, the reversing cylinder on each car can be brought into either a forward or reversed position, by sending current through two large magnets, with plungers. The cylinder remains in the desired position, so long as current is kept on, a spring pulling it sharply to the off position, when current is taken off. One of the magnets is used for the forward, and the other for the reverse, position.

The main cylinder on each controller, having a more extended motion than the reversing cylinder, is operated by a small reversible pilot motor, through a worm-reduction gear. By means of a very ingenious spring clutch, intermittent quick forward or backward impulses are given to the cylinder, so as to give quick breaks to the various contacts, as they pass the controller fingers.

The small operating currents, for the magnets and pilot motors, are taken from the line, and are switched on, in their correct sequence, by means of a miniature controller, called the master controller, before mentioned. These master controllers only weigh about 22 lbs. each, and one is provided on the front and rear platforms of each car. They are all connected together, throughout the entire train, by means of a multiple cable, and flexible connections and plugs, which can only be joined together in

the correct way, on account of the mechanical arrangement of the contacts.

This description is necessarily a very brief one, and does not enumerate all the ingenious devices which have been introduced to render the system automatic and self-locking. A very full description is given in the *Street Railway Journal* for May 1901.

Advantages and Disadvantages of Multiple-unit Systems.—Among the many advantages to be obtained by the multiple-unit system are—(1) The master controller is an exceedingly simple and easy one to work, practically no force being required to operate it. (2) The front and rear platforms are not blocked by large main controllers. (3) As the latter are usually placed under the cars, there is not the same restriction as to size, and therefore ample provision can be made for the heavy currents, and long breaks can be given at the various contacts.

The disadvantages are the increased cost, and the natural objection to the multiplicity of small operating parts and contacts. Notwithstanding these inherent weaknesses, the multiple-unit system has much to recommend it, particularly from the point of view of the spreading of the weight of the motors throughout the train, and there is no doubt that it will have very extended use in the future. Its first application was on the Chicago Elevated Railway in 1896, and its success has been followed by the designing of similar systems, by the Westinghouse Co. of Pittsburg, and the General Electric Co. of Schenectady.

The Westinghouse System.—The Westinghouse system differs considerably in detail from that of Mr. Sprague. An ordinary hand-operated controller, of a suitable size for the motor equipment, is placed on each car, and being of a long, upright type, it cannot well be accommodated under-

neath the car body. This controller is worked, in the one direction, by pawls and ratchets, and, in the other, by a rack and pinion, giving a quick throw-off for breaking the circuit. These devices are themselves worked by means of compressed air, the air being taken from the compressed air cylinders used for working the brakes (assuming that the car is fitted with such appliances).

A small controlling switch is placed on the front and rear platforms of every car, and is connected through a multiple cable with a small battery, and with a number of small magnets on each main controller, which operate air valves, admitting the compressed air to work the pawls and ratchets or the rack and pinion. An ingenious interlock is made with the air brakes, when such are used, the air, which operates them, automatically cutting off the current, at each controller, immediately the brake is applied.

The General Electric System.—The General Electric Co. have attacked the problem in a different way to those mentioned above. Instead of providing a controller on each car, and operating this from a distance, they use a number of circuit breakers with shunt solenoids. By means of these circuit breakers, and according to the number of them operated at once, all the combinations of circuits, etc., which may be required, are obtained.

The circuit breakers are put into action, by means of a small master controller, which operates the shunt solenoids. Each car has its own group of circuit breakers, the solenoids being connected on the one side to a multiple cable which goes through the train, and on the other to an earth connection through a high resistance. There is a master controller on each platform of each car, so connected to the system that either may be used.

Multiple-unit control systems, by means of centrally-operated controllers, are necessarily in more or less a transitory state. Being new, the details, briefly indicated above, will doubtless be varied and improved, from time to time, as the systems develop in practical work.

CHAPTER VII.

ROLLING STOCK.

Selection—Large v. Small cars—Single v. double deck cars—Combination car—Car construction—Platforms—Stairways—Seats—Lighting—Heating—Single trucks—Bogie trucks—Frames and bearings—Chilled iron wheels—Steel tyred wheels—Shoe brakes—Air brakes—Slipper brakes—Electric brakes—Sand boxes—Life guards—Speed—Signalling—Colours of cars—Destination indicators—Car housing—Car pits—Traversers.

Selection.—Upon the selection of the rolling stock depends, to a large extent, the popularity, or otherwise, of any electric tramway or railway system. The increased speed, which electric traction renders possible, is no doubt a very important factor, but, to a large proportion of the riding public, the comfort of the journey depends upon the type and character of the car itself.

The possibilities of electric traction, in the way of higher speed, larger cars, and better lighting, have led to the designing of cars, which, compared with the old type of horse car, are greatly superior. The passenger takes little interest in the power station, or the distributing system, the rolling stock being that only which appeals to him. Therefore, the best type to use is a matter worthy of the most serious attention of the traction authorities.

Large v. Small cars.—The correct type of car must depend upon the kind of service for which it is to be

used. It was pointed out, in Chap. I., that large cars were much more efficient than small ones, and this is perfectly true, provided that we are able to fill the cars during a large portion of the day. But, when the service is, for the greater part, within a densely-populated district, where frequent stops have to be made, it is a question whether smaller cars, and more of them, would not be better. A considerable time is often taken by a passenger, when the car is a large one, in getting, say, from the front end to the rear platform, in order to alight, and, during this time, the car, with its passengers, is kept at a standstill. When halfpenny fares, with short stages, are in operation, it is a most difficult matter for the conductor to get through the car, to collect the fares, before the end of the stage is reached, and he thus has, practically, no time to attend to the work of assisting the passengers in getting on or off.

Speaking broadly, we may say that small cars are the correct ones to use, where the service is a purely local one, with short stages and frequent stops, and that large cars are better, when the service is more in the nature of a suburban one, and where long distances can be run without stops.

Single v. Double deck cars.—But this again depends somewhat on whether the cars be double or single decked, *i. e.* with or without top seats, and, if the former, whether they be open or closed cars. Excepting in England, the use of single deck cars is practically universal, and those who have had the largest experience in electric traction work, are almost unanimous in their preference for them. On account of the large number of omnibuses running in English cities, people have developed a liking for roof seats, and, rightly or wrongly, this preference has been

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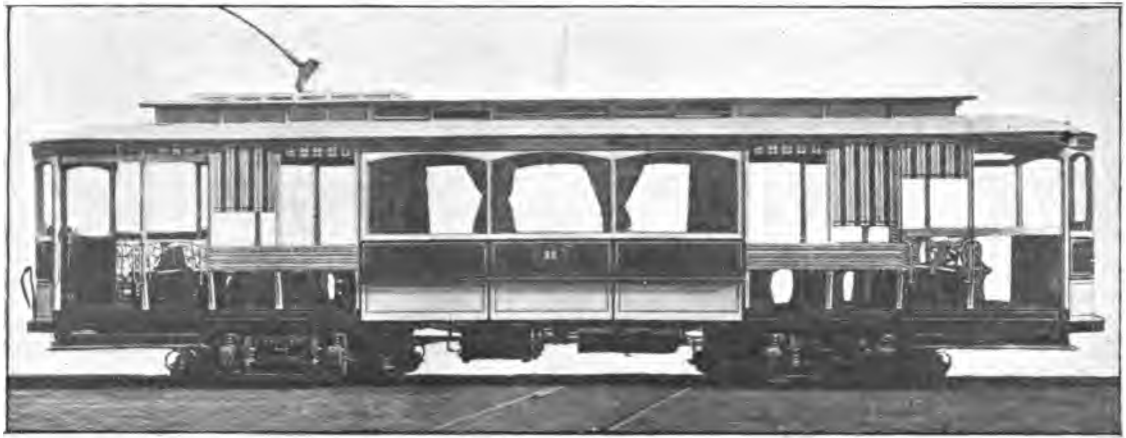
Fig. 69



COMBINATION OPEN AND CLOSED CAR

encouraged, by the adoption of double deck cars, on nearly all the electric tramways so far established in England.

The advantages, that the single deck car possesses over the double deck car, are, (1) the much shorter space of time in which the car can be emptied and filled, (2) the greater ease with which the conductor can collect the fares, as he has no stairway to climb, (3) the greater height which can be allowed in the interior of the car, (4) the much lighter construction which can be employed in the roof.

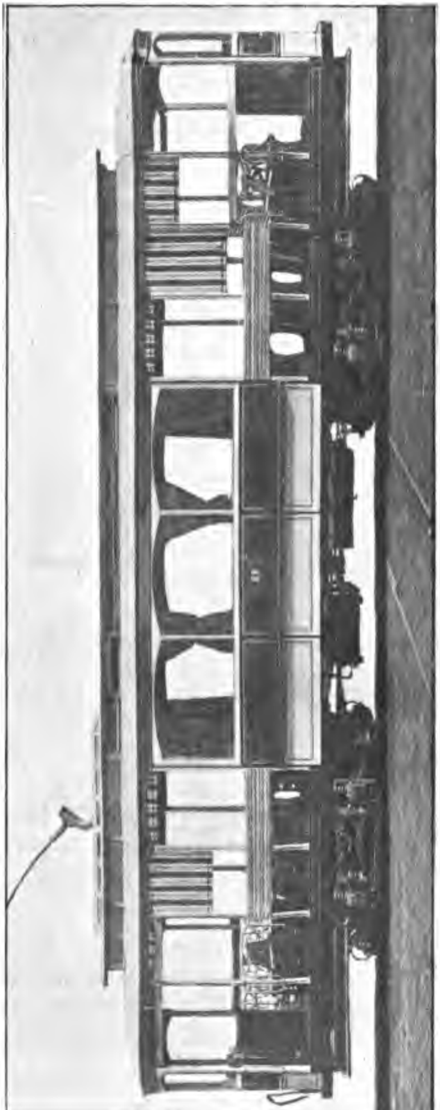
The single deck car has, of course, to be longer than the double deck car, to accommodate the same number of passengers, but, as the majority of cars in England are used for town service, for the reasons mentioned above, the car carrying less passengers is preferable, and this the single deck car more easily provides.

In America, single deck cars are made in two types, one an open car, and the other a closed one. The former is used entirely for summer traffic, and the latter for winter traffic. This means that two complete sets of cars, or, at any rate, of car bodies, have to be provided. The climatic conditions, however, are such that neither open cars nor cars with top seats could be used during the winter, and, in the summer, the closed car is not nearly so pleasant to ride in as the open car.

In a much smaller degree these conditions hold good in England The open car would be very objectionable during the winter, and the closed car would be but a poor substitute for the outside seats now in common use.

Combination Car.—Recognizing these difficulties, and also the advantages to be gained with the single deck car, a type of composite car has been introduced, which has a number of good points.

Fig. 69



COMBINATION OPEN AND CLOSED CAR

This car, which is shown in Fig. 69, has a closed body in the central portion, and open seats at either end. The open parts of the car can be closed, to a large extent, by means of blinds, which serve both as a protection from the sun and also from the rain.

A car of this kind has, practically, all the advantages which can be claimed for the double deck car, in that it provides open seats as well as closed ones. The car in the illustration has a seating capacity for 54 passengers, which is about the same as the average double deck car. The open seats can be used equally well, in either wet or dry weather, whereas the top seats of a double deck car are not of much service in the former case. So-called dry seats have been invented, almost without number, but, at the best, they are only a makeshift, and, if a roof could only be put over the outside seats in wet weather, they would be largely patronized. The combination car, just described, has a roof over the open seats, and is, therefore, in this respect, much superior to a double deck car.

Car Construction.—Car construction has now become fairly well standardized, and there are several good makers, who may be relied upon to turn out a satisfactory car, practically without a detailed specification being required.

One of the great points in car construction is to see that nothing but well-seasoned timber is used. Modern electric cars have to stand very heavy strains, and are exposed to all kinds of climatic conditions. Most makers keep a very large stock of the timber required, so that they may be certain it is naturally dried, and not stove dried. Oak, pine, teak and ash are the principal woods used, but steel is coming largely to the front in the construction of the lower framing.

Fig. 70.

CAR WITH ORDINARY STAIRWAY.

Platforms.—The platforms, at either end of an electric car, are much larger than sufficed for the old horse car, since space has to be provided for the controller and other gear. In some cases the end platforms are closed in, so that the motorman is standing within what is practically a glazed vestibule. The idea of this is to protect him from the weather, and its principal use is to keep the rain off. But, if the windows be shut during wet weather, the glass becomes covered with rain spots, and the motorman cannot see properly where he is driving. Practically, therefore, when the windows would be of most service, they are a disadvantage, and experience shows that a vestibuled car is not the most satisfactory.

Stairways.—Double deck cars require a stairway at either end, to give access to the roof. The ordinary type of stairway is shown in Fig. 70. This is similar to the familiar one on omnibuses and horse cars. Its disadvantage is that the passenger may easily be thrown into the road, if the car should start suddenly while he was ascending or descending. A type of stairway, known as the reversed stairway, was introduced a few years ago, and has since become very popular. It is shown in Fig. 71. It will be seen that the passenger is well protected, and that the use of this reversed stairway allows the car roof to be extended right over the platforms, thus giving additional top seating accommodation.

The first sight of such a double deck car, with its extended roof and reversed stairway, after any lengthened experience with such single deck cars as are common in the United States, always gives one the impression, that the former are top-heavy and cumbersome vehicles. On the other hand, the first sight of the American car has entirely the opposite effect. In the Author's opinion,

Fig. 71.

CAR WITH REVERSED STAIRWAY.

English prejudices notwithstanding, it is only a question of time for single deck cars to replace double deck cars, in the United Kingdom.

Seats.—The inside seats of a car should be made as plain as possible, consistent with reasonable comfort. All such luxuries as upholstered seats should be excluded, as they are most difficult to keep clean. It has been said that, by the use of upholstery, cars often carry passengers which do not pay any fares, and there is no doubt that there is a great deal of truth in this suggestion. One does not usually sit long enough in a car to require anything but a well-shaped plain seat. The shape of the seat has more to do with the comfort of it than is often imagined.

The inside seats are generally two in number, arranged one on each side of the car, with a centre gangway. The outside seats are of the garden pattern, with reversible backs, arranged across the roof, with a gangway. The exact disposition depends, largely, upon the width of the car.*

Lighting.—One of the great contrasts, between an electric and a horse car, is in the matter of lighting. Instead of a feeble oil lamp at either end, from 10 to 20 incandescent electric lamps, of 16 c.p. each, are frequently used, and passengers can read with comfort at any part of the car. The lamps are run in series of five, direct from the line circuit. Head lights on either dash-board, and roof lights on short standards, are generally included, being connected in the same circuits with the interior lamps. The wiring should always be carried out on at least two circuits, with alternate lamps on each, so that, in the event of a lamp failing and putting out one series, the

* See page 213, Chap. VIII.

Fig. 72.

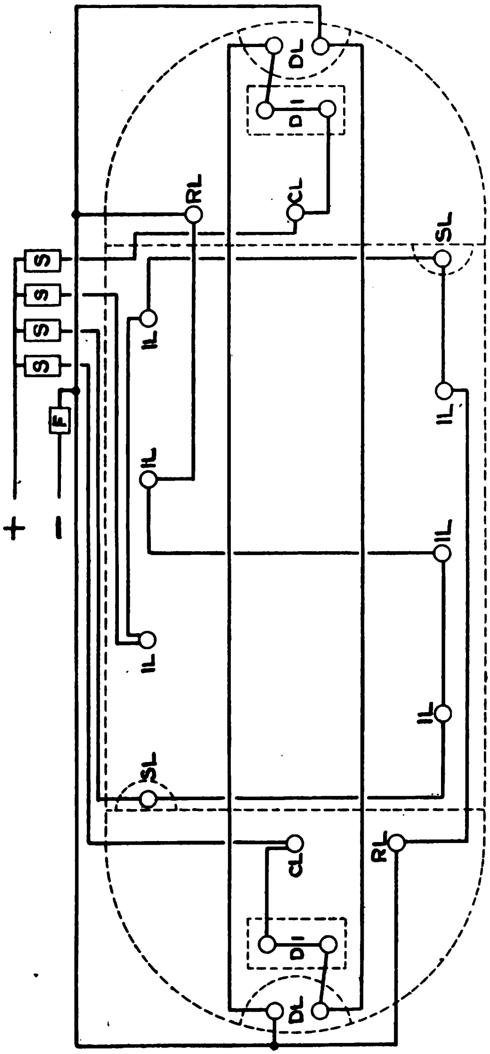


DIAGRAM OF WIRING FOR CAR LAMPS.

S = Combined Switch and Fuse.
F = Fuse.
IL = Interior Light.
SL = Signal Light.
RL = Roof Light.
CL = Canopy Light.
DL = Dash Light.
DI = Destination Indicator.

other set would still be in effective use. A plan is shown in Fig. 72, with the positions of the lamps and the wiring indicated, but there are many good alternative arrangements.

Heating.—In this country, there is not much necessity for warming the cars during the winter months, but, in Canada, and parts of the United States, car heating is a very important consideration. It is generally carried out by means of electric radiators, or heaters, placed under the seats, and the amount of energy required, to keep these in operation, is quite a large proportion of the total energy taken from the generating station. An ingenious method is now adopted on some lines, whereby this energy is largely reduced. The electric heaters are so arranged, that they may be used as the resistances, in connection with the controllers. The energy wasted, in starting and stopping the car, is therefore used to advantage in heating the car. The ordinary resistances, however, which are usually placed under the body of the car, are still required for use in the summer months, when the heating apparatus is not wanted inside the car.

Single Trucks.—While the smooth running of tramcars depends to a very large extent upon a proper road bed, yet the type of truck used has a good deal to do with the matter. The greater length, and heavier weight, of an electric car, combined with the higher speed at which it travels, make the choice of truck a very important matter.

Trucks are usually divided into two classes, (1) single trucks, having four wheels, and (2) double trucks, having eight wheels. For cars up to about 30 ft. in length over all, a four-wheel truck, with rigid wheel base, is generally adopted, but, for cars of a greater length, double or bogie

trucks are essential, in order that the car may travel easily round curves.

The distance between the two axles of a four-wheel truck is called the wheel base, and is seldom over 7 ft. in length, for ordinary town traffic. A wheel base of 5 ft. 6 in. is about the smallest which is ever used, and, unless the car body is short, it will be found that steady running cannot be obtained with such a small wheel base, on account of the fore and aft oscillation, which takes place at any reasonable speed. The length of the wheel base must be determined largely by the smallest curve on the line, and, in order to obtain a good working wheel base, the curves of the track should be kept as large as possible. Anything below 50 ft. radius will be found to cause trouble, and great wear, with single truck cars.

Bogie Trucks.—To overcome the difficulty of sharp curves, where large cars must be used, bogie trucks are necessary. Each truck, with its four wheels, is so mounted that it can swivel under the car, and accommodate itself to the track, without strain to the car body, as it passes round the curves. But the use of bogie trucks involves several disadvantages. As two motors only are generally employed on a car, and as each motor is suspended on one of the axles, it is not possible to drive by all four axles, and so there is a great tendency for the driving wheels to slip, since a large portion of the weight of the car is carried upon the trailing axles.

A type of bogie, called a maximum traction truck, has been introduced in order to meet this difficulty. Its general characteristics may be seen from Fig. 73. Instead of having four equal wheels, with the car supported over the centre of the truck, it has two driving wheels, usually of 30 in. diameter, and two smaller wheels, called pony

wheels, usually of 22 in. diameter. The car is carried from a point nearly over the axle of the driving wheels, with the result that as much as 80% of the weight of the car can be

Fig. 73.

MAXIMUM TRACTION TRUCK.

utilized, in obtaining adhesion to the rails. The pony wheels simply act as guiders, and as they carry only a small proportion of the weight of the car, they are rather

apt to rise out of the rail groove, when the truck is taking a curve. Attempts have been made to remove this difficulty, by arranging that the swing of the car body puts more weight upon the pony wheels at that time, but experience has shown that the chief difficulties, which are experienced with maximum traction trucks, have not yet been overcome, and that, not only do they give frequent trouble, by derailing at curves, but, on heavy grades, the driving wheels are very likely to slip, since the whole weight of the car cannot be carried upon them. Rapid acceleration is not possible with maximum traction trucks, for the latter reason, and their use thus deprives a car of one of its most essential features.

These difficulties can be practically removed by using bogie trucks with four equal wheels, and with two motors per truck. By these means all the wheels become drivers, they are not liable to slip, and, as the weight is equally divided, there is no more risk of derailment than with the ordinary four-wheel car. But the adoption of four motors per car increases the cost of equipment, and the liability of breakdowns, since there are four motors to go wrong instead of two. The use of four motors, in this way, does not necessitate a four-motor controller. The two motors, on either truck, are coupled together electrically, and are treated as one motor by the controller.

The whole question of the correct type of truck is not yet settled, but, for ordinary traffic, a moderately short car, with a four-wheel single truck and two motors, will be found to give the best all-round results.

Frames and Bearings.—The details of truck construction are rapidly becoming standardized. The side frames are preferably made of forged steel, in one piece, although

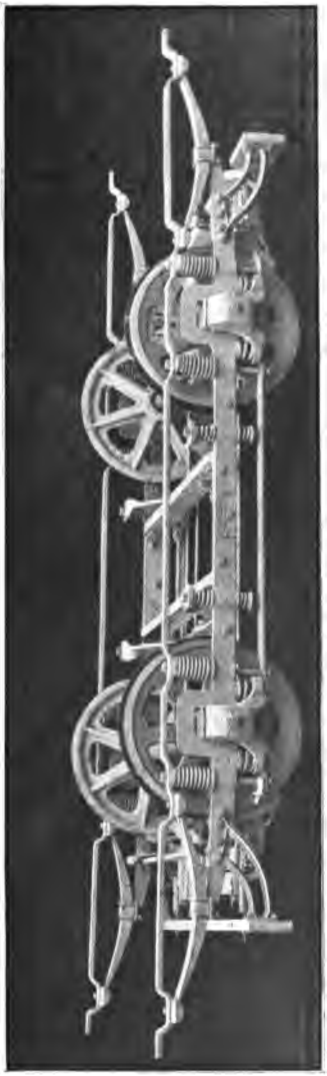


Fig. 74.

SINGLE FOUR-WHEELED TRUCK.

some makers still build up the frames by riveting the various parts together, while others use cast-steel parts. The arrangement of springs is very important, and one which largely determines the life of the car body and the motors. A well-known type of four-wheel single truck is shown in Fig. 74, from which its characteristic features can be seen. The great length of the car, for the comparatively short wheel base, necessitates struts at either end to carry the car body. These struts can either be a rigid cantilever bar, or bow springs as in the illustration. Sometimes a combination of both is used. The axle boxes support the truck by addi-

tional springs, and are made to slide freely within the side frames.

The bearings, for the car axles, consist of an upper half only, since the weight of the car is always in a downward direction. The lower part of the axle box is formed into a cavity, which holds a store of oil. This is carried to the bearing by means of a felt pad, pressed up to the axle by springs.

It is very essential that the truck should be both flexible and rigid. Flexible, so that it will give in certain directions to the strains caused when going round a curve, and rigid, so that it may be kept square, and in alignment, without having to depend upon the car body itself in any way. The attachment to the car body is usually made by bolting the top bar of the truck, on either side, to the car framework. This should be done in such a way that, while the car body is securely held, it is not a difficult matter to remove it, in a short space of time, in the car shed, should it become necessary. Sufficient attention is not always paid to cross bracing, so that the two sides of the truck are kept parallel. Unequal wear of the wheels often takes place, due to nothing else but a general twist of the truck.

Chilled iron Wheels.—The axles should always be of steel, made by the open hearth process, and having a tensile strength of not less than 28 tons per sq. in. The wheels are pressed into place, on their axles, by hydraulic pressure, so that no keys, or other fixing devices, are necessary. Cast-iron wheels, with chilled rims, have had an extended service, but recent experience in some towns has gone to show, that a wheel with steel tyres is often preferable. Chilled wheels, while very hard, have given trouble through the flanges chipping, and occasionally through the rims and spokes cracking. It is likely that

these accidents have been due partly to an imperfect track, but, it is practically certain, that if steel tyred wheels had been used, they could not have occurred. It is very difficult to be certain that the chill is uniform, or that the strains are equally spread, all over the wheel.

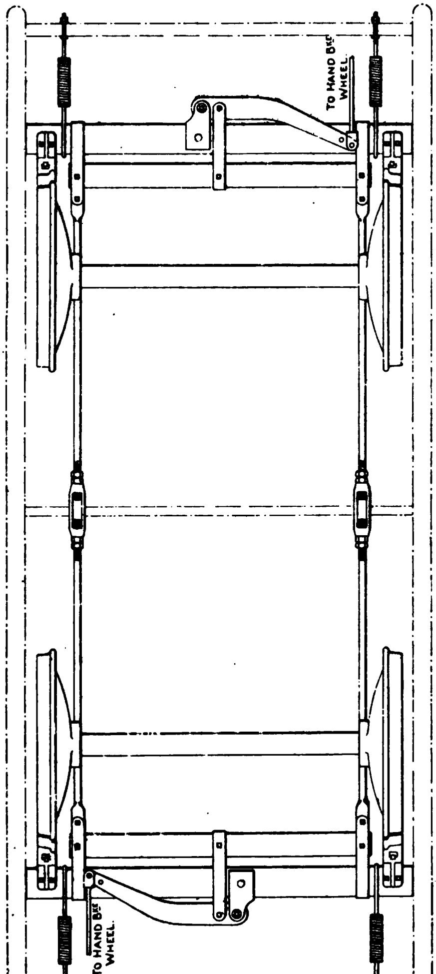
Steel tyred Wheels.—Wheels, with the body of wrought-iron, and with the rim of steel, shrunk into place, and then bolted, have given generally satisfactory results. They do not chip, they can be turned up in a lathe, the rims can be renewed when necessary, and, although dearer in first cost, yet the longer life obtained by them, often makes them cheaper and more satisfactory, in the long run.

Shoe brakes.—Following the practice of horse traction, the only type of brake, with which the first electric cars were equipped, was the ordinary shoe brake, worked by hand. A little experience soon proved that there was a marked difference, between controlling a car travelling at six miles an hour, and one travelling at, perhaps, twice that speed. There is always a certain amount of slack to be taken up by the hand wheel, before the brake shoes come into contact with the wheels, and, although this operation can be performed quite as quickly with an electric car as with a horse car, yet, with the former, the distance moved by the car, before the brakes come into operation, would be twice that of the horse car, without reckoning the longer time it takes to bring the car to a standstill. The brake mechanism had, therefore, to be made not only quicker in action, but also more powerful, and this the ordinary hand brake is hardly capable of accomplishing. Still, it is a most necessary adjunct to every car.

The hand brake consists of cast-iron shoes, which are carried on a self-adjusting frame, within a small distance

of the rims of the wheels. The frame is so arranged, that

Fig. 75.



PLAN OF HAND BRAKE FRAMEWORK.

all four shoes press equally against the wheels, notwith-

standing inequalities in the wear. Fig. 75 shows, in plan, the framework of the brake in its position on the truck. It will be seen that the brake can be applied from either platform, and that an adjustment is provided, for taking up the slack, when the shoes wear.

In order that the motorman may be able to exert his full power, in putting on the brake, the brake handle is often arranged with a ratchet, so that, instead of having to turn the handle round in circles, he may be able to make a backward and forward motion of the handle, and so put on the brakes direct, at the most convenient position of the handle.

As the brake shoes wear rapidly in actual service, means must be provided for quickly replacing them, and a store of brake shoes should be provided in the car shed. Cast-iron is about the most satisfactory material to use, although it is subject to rapid wear. But it is cheaper to renew brake shoes than wheels.

One of the troubles, in the use of the ordinary hand brake, is that the driver is very apt to put the brake on too hard, and thus to lock the wheels. A locked wheel is of very little use for braking, and the only result is to wear flats upon the rims. It is difficult to make the ordinary driver understand, that the brake is working at its best, when the wheels are just revolving, and he should be most carefully instructed, in case he finds the car wheels locked, to take the brake off immediately, and to apply it a second time, with less force.

Air brakes.—Although it is possible to apply a hand brake so powerfully as to lock the wheels, yet the work becomes very trying to the driver, particularly on hilly roads. Various types of power brakes have been introduced, not only for the purpose of better control, but also to relieve

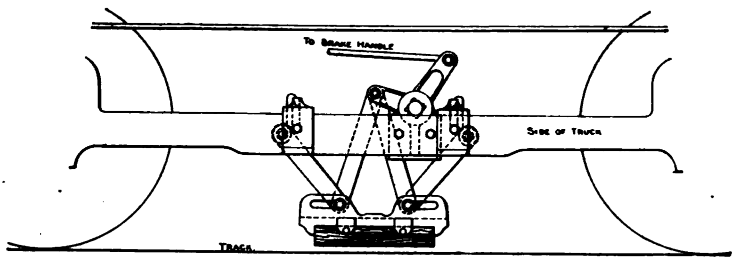
the driver, as much as possible, from the strains of working the hand brake. One of the earliest types of power brake was that worked by compressed air. The equipment of an air brake consists of compressors, reservoirs, and brake cylinders, and is rather a complicated addition to the gear of the car, besides a great increase to the dead weight to be carried.

The air compressor can be worked in two ways, (1) by means of an eccentric on one of the car axles, and (2) by means of a small auxiliary electric motor. With the former, it is necessary to provide an automatic relief, since the compressor is working the whole time the car is running. With the latter, there is an automatic relay, whereby the motor is started and stopped, according to the pressure of air in the reservoir. The compressed air is used to operate the brake shoes, by means of a cylinder, with pistons connected directly to the brake levers. With the air brake, it is possible to exert great pressure upon the wheels, but the braking power is just the same as when worked by the motorman, the advantages being the ease of working, and the comparative quickness of time in which the brake can be applied. Experience with air brakes shows, that the driver is apt to put on far more pressure than is necessary, and that flats are of frequent occurrence.

Slipper brakes.—Cars, which have to run on roads with heavy grades, are frequently equipped with an additional brake, known as a slipper brake. This brake consists of a block of wood measuring about 12 in. × 2 in. which is pressed on to the track rail, at each side of the car. Fig. 76 illustrates such a brake, and the mechanism, by which the pressure is applied, will be clear. The slipper brake is generally worked by a hand wheel on either platform, arranged in conjunction with the shoe brake lever. The

tendency of such brakes is, of course, to lift the car wheels from the track, and therefore to take the whole of the weight of the car upon themselves. The area of contact between the brake slippers and the track is comparatively great, and a larger braking effect is obtained, and that without in any way wearing the wheels, or causing flats. Slipper brakes take a deal of power to put on properly, and are rather a severe strain upon the driver. Compressed air has recently been tried with success, and is a great improvement upon the ordinary hand wheel, although

Fig. 76.

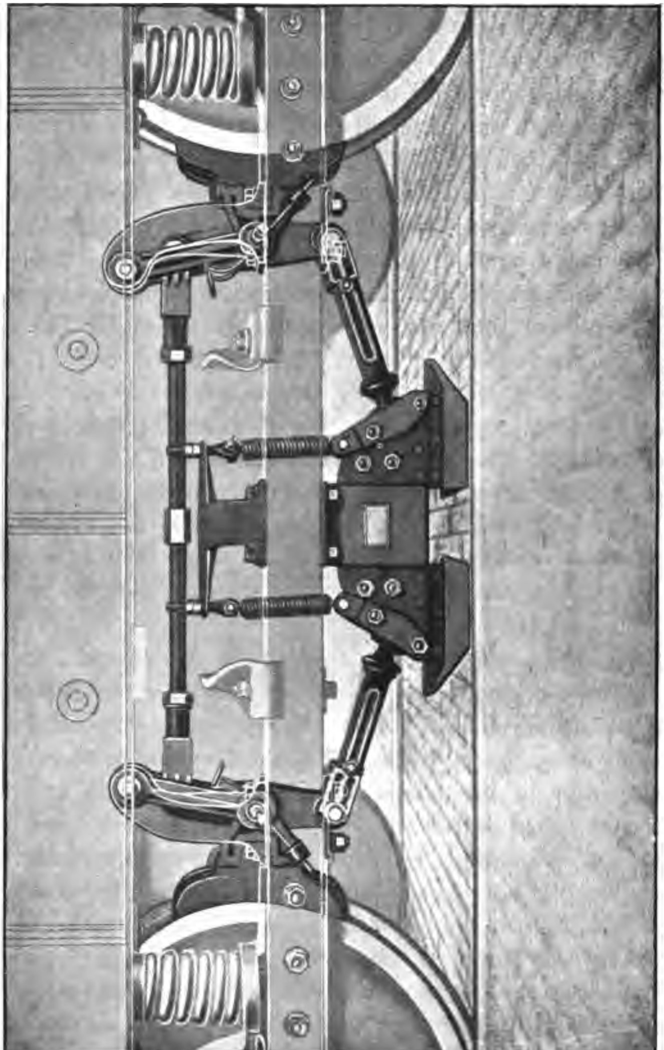


MECHANISM OF SLIPPER BRAKE.

the cost and weight of the equipment must not be lost sight of.

Electric brakes.—In Chap. VI. the use of the motors themselves for braking was mentioned. An ingenious use has been made of the motors, in a brake called the Westinghouse magnetic brake. This is really a composite brake, as it consists of a shoe brake, a slipper brake, and a motor brake. In Fig. 77 a view of this brake is given, from which it will be seen that a slipper is suspended over the track, and that it is connected by levers to the ordinary wheel shoes. The slipper is made of iron, and is wound with a coil of wire, which is connected to the

Fig. 77.



WESTINGHOUSE MAGNETIC BRAKE.

motors, when the controller is put into the braking position. When the brake is in action, the current from the motors (working as dynamos) makes the slipper into a powerful magnet, and it is attracted, with considerable force, down to the track rail. This motion forces the brake shoes against the wheels, and so we have three braking effects in operation at the same time. The motors tend to stop, because they are acting as generators; the slipper brake tends to stop the car, because of its friction on the rail; and the shoe brakes tend to stop the wheels in the ordinary manner. This brake is one of the most powerful, and effective, which has yet been devised.

By means of the controller, this effect can be graded, depending only upon the number of controller stops, and the operation calls for no labour on the part of the driver. The Author has witnessed trials of this brake, on a road at Pittsburg, U.S.A., where the grade is 1 in 12. A heavy car, running down the hill at a speed of twenty miles per hour, was pulled up, without jar or shock, within its own length.

Sand boxes.—Whichever type of brake is used, its successful working depends, to a very large extent, upon the condition of the track. A dry track gives little trouble, but a greasy track makes the stopping of the car a very difficult task, since the wheels tend to slip upon the greasy surface, when the brake is applied. Sand boxes are, therefore, a necessary part of the car equipment. They are generally placed under the seats, and, by means of a flexible tube, the sand is led down to the track rail, immediately in front of the wheels.

Sand boxes are essentially simple things, but, unless one is used which has an efficient valve arrangement, it may prove useless when most required. It frequently

happens that, with ordinary sand boxes, the valve sticks, thus letting out all the sand, the first time it is used. Then, when the emergency comes, the sand is not available, and more than one accident has been caused by this reason. One of the best types of sand box is that known as the Ham sand box. The valve, in this box, only allows a small quantity of sand to pass at one time, and a continual movement of the valve is therefore necessary to obtain a continued flow. But this is far preferable than having a much larger quantity flow than is required. The sand box is worked by means of a small pedal, under the driver's foot, connected to a lever on the valve of the box. The correct kind of sand is one which is not too fine, and it must be well dried before being used, so that it may not clog in the box.

Life guards.—In order to save life, should any person fall upon the track, in front of an approaching car, the Board of Trade insists that each car should carry some kind of life guard, with the object of catching the person, before he could get beneath the wheels. There are various types of life guards on the market, none being entirely satisfactory, but several being more or less so.

Life guards may be divided into two types, the one being brought into action by the driver of the car, and the other by the person who is lying on the track. It is not possible always to keep the life guard down upon the road, since it would not only rapidly wear out, but it would be very liable to catch in the paving, and other obstructions, and so become damaged. The guard is, therefore, usually held a few inches above the track, and, to make it operative, it must be lowered to the track when required. If the driver is relied upon for this, it is certain that, at some time or another, he will be too late in lowering the guard,

and, therefore, that type in which the guard is lowered by the person in danger, is the better. A guard of this kind is illustrated in Figs. 78 and 79.

The guard proper is suspended a few inches above the track, and, hanging in front of it, is a kind of swivel gate. If this gate be pushed inwards, as must happen if a person strike it, the guard itself immediately falls on to the track, and so picks up the object.

However satisfactory life guards may be, they should never be relied upon. The best way to avoid injury to persons is to have reliable brakes, and a steady, careful driver.

Speed.—The maximum speed, allowed by the Board of Trade for electric cars in urban districts, is 12 miles an hour, and, in some towns, only eight miles an hour. Cars are run habitually, and with perfect safety, at far higher speeds than this, and it is quite time that the Board of Trade limit should be raised. The maximum safe speed depends entirely upon the brake power available, and the Local Authority, knowing the local conditions, is in a much better position to decide the safe limit, in each case, than is the Board of Trade. Sixteen miles an hour is a perfectly safe speed on most roads.

Signalling.—Two distinct methods of signalling are required for electric cars, one, by means of which either the conductor or the driver can signal to each other, or the passengers can signal to the conductor, and the other, by means of which the driver can give warning of the approach of the car. The first arrangement was formerly a mechanical one, but, in recent years, electric bells have been used with much more satisfactory results. It is usual to place a number of pushes inside the car, and, in some cases, on the top of the car as well. The push on

each platform should ring the bell on the other platform only, while the pushes inside, and on the top, are generally divided, one half being connected to the bell on the front platform, and the other half to the bell on the rear platform.

The wiring for these signal bells requires to be very carefully carried out, as a failure may cause great inconvenience. The wires are carried in the false roof of the car, and the battery is placed under one of the seats. Any good type of semi-dry, or dry, cell will answer very well. As to whether the bells should be of the trembling pattern or not, depends very much upon the quality of the bell. Cheap trembling bells are very apt to go wrong, and some makers, therefore, prefer to fit nothing but single stroke bells.

The signal bell, used by the driver, consists of a large steel gong, fixed on the underside of the car platform, and it is worked by a pedal from the driver's foot. Both the sand box, and the signal gong, are worked by pedals with removable plungers. These are taken to the other end of the car, when the driver changes his position. Many drivers are in the habit of using their signal gongs far too frequently, with the result that the electric car becomes more or less of a nuisance in a quiet neighbourhood. There should be no need to ring the signal gong, unless it is necessary to clear the way, or to give notice of the approach of the car, before passing round a curve. But, in any case, one or two strokes should be sufficient for the purpose.

Colours of Cars.—A matter upon which there is a division of opinion, is whether cars on any system should be painted an uniform colour, or whether each distinct route should have its own distinguishing colour. Follow-

ing the practice which has prevailed so long with omnibuses, many people say that distinctive colours is the best method. But, if this be adopted, it means having spare cars for each route, as to use a car painted for one route upon a different route, would be to sacrifice the whole principle, and would make confusion certain. It would certainly appear to be the better way to paint all the cars the same colour, and to use some distinguishing mark, which should be easily removable, for the various routes.

Passengers require to distinguish cars, as much in the night time as in the day time. Different car body colours are of no service at night, and, therefore, coloured lights are always used. The colours of these lights can be readily changed, to suit any route, and, in the same way, if destination or route indicators, of a distinctive pattern or colour, were used in the day time, there would be no difficulty in distinguishing cars, even though they were all painted the same colour. The great advantage of this course is, that only one set of spare cars is needed, the destination and route indicators being changed, in a few minutes, when required.

Destination indicators.—It is usual to place a destination indicator on the front and rear of the car, immediately over the canopy. This indicator should show merely the destination of the car. The route taken by the car should be shown upon a long narrow board, immediately over the car windows.

One of the neatest, and most effective, destination indicators, which has been introduced, consists of a light metal box, having a glass front. Within the box, and carried upon a couple of rollers, is a linen blind, which stretches across the front, immediately behind the glass.

The body of the blind is painted an opaque black, leaving the letters of the word in a semi-transparent white. The white letters, on a black ground, are easily read at a

Fig. 80.

ILLUMINATED DESTINATION INDICATOR.

considerable distance in the day time. At night the blind is illuminated, from the interior of the box, by a couple of incandescent lamps, which throw up the white

letters in strong relief. One of these destination indicators is shown in Fig. 80. The blind can be made of almost any length, and, by means of a small handle, can be rolled and unrolled, to show any word which may be upon it.

Car housing.—An important question, in connection with electric cars, is their housing. The positions of the car sheds, for any system, require to be most carefully chosen. A spot in the centre of the system should be obtained, if at all possible, as otherwise, when there are a number of routes, a considerable amount of dead mileage will have to be run every day, in taking the cars to and from their respective routes.

Car sheds should not be too large in size. The correct size will depend upon the system itself, and upon local conditions. Sheds, with less than 100 cars, are comparatively expensive to maintain, and sheds, with over say 200 cars, become too cumbersome to handle properly, unless a number of independent exits can be obtained. It is seldom that more than one entrance is possible, and, as all the cars have to use that entrance, a considerable time is taken to get the cars in and out. For this reason it is not wise to have a car shed too large.

Car pits.—Each track, or at any rate the large majority of tracks, within the shed, should be provided with a pit. The pits must be deep enough for a man to walk comfortably under the car, and they should be well drained, and kept perfectly clean. An excellent arrangement is to carry the whole of the tracks, within the shed, upon brick piers, or iron columns, thus leaving the whole of the substructure open. The spaces between the tracks are, of course, covered over, in order to provide working and walking space.

Certain of the pits should be specially kept as repair pits, the others being used for general cleaning purposes only. It is convenient to have a second line of rails at the bottom of the repair pit, on which small bogies can be run, for removing parts of motors, etc. It is often necessary to lower a pair of wheels, and an axle, into the pit, and this can be done by having parts of the track rails removable, so that when the car and truck are jacked up, the pieces of track rail can be shifted, and the wheels and axle lowered.

A well-equipped workshop should be provided in every car shed, one of the bays being often taken for the purpose. Cars should undergo a systematic overhaul, and should be taken through the repair shops, at least once in every twelve months. By adopting a certain order in the arrangement and working of the cars, this can be readily carried out.

Traversers.—When there are a large number of parallel tracks in a shed, and only a few entrances or exits, a very complicated set of points and crossings is necessary, in order to divert cars to the various tracks. A favourite method of getting over the difficulties of points and crossings, is to use a traverser, which is a travelling carriage running at right angles to the tracks, by which the cars can be carried across the shed, to whatever line of tracks it is desired to use. The traverser is worked by an electric motor, and, in the hands of an experienced man, it is possible to shift the cars at a good speed. In large sheds, however, it is often necessary to use two traversers, to save time. The whole question of the arrangement of the shed, the use of traversers, points, etc., depends entirely upon the land available, and other local conditions.

CHAPTER VIII

PERMANENT WAY

General—Gauge—Influence of Gauge on Passenger Accommodation—Types of Rails—The Girder Rail—Weight of Rails—Rail Grooves.—T-headed rails—Rail Joints—Continuous Rails—Electrically-welded Rails—Cast-welded Rails—Points and Crossings—Interlacing Lines—Curves—Laying Rails—The Rail as a Conductor—Bonding—The Chicago Bond—The Neptune Bond—The Crown Bond—The Columbia Bond—The Edison-Brown Bond—Cleaning the Track—Resistance of Bonded Joints.

General.—The broad distinction between an ordinary road vehicle, and a tramcar or railway-carriage, is that, while the former runs upon the macadamized or paved road surface, the latter travels upon a specially laid "way." The object of using a special way is simply to reduce the tractive resistance, and the wheels are always flanged, in order to keep them to the prescribed track. No steering apparatus is required in consequence.

The tractive resistance, on an ordinary road, often amounts to 50 lbs. per ton, and, as the condition of the road surface is constantly varying, it will be readily seen that the amount of power required to overcome tractive resistance will vary largely also. The advantages to be gained by the use of a smooth track are self-evident, and the persistency with which drivers of vehicles in our towns keep to the tramway rails, shows that they are fully alive to the easier running to be obtained thereby.

In practically all street tramways and railways the single track consists of two rails laid parallel to each other, and, unless within a fenced or enclosed route, they must be kept

at the level of the street, in order that the traffic may pass freely in any direction. To take the flanged wheels of the cars a continuous groove must be formed, either at the side of the rail, or, as is usually the case, in the face of the rail itself. The groove must, in any case, be deep enough to allow the flange of the wheel to clear the bottom.

Gauge.—The distance measured across the track, between the inside edges of the tread of the rails, is called the "gauge" of the line. The standard gauge is 4 ft. $8\frac{1}{2}$ in., being that of the main railway lines, but there are a number of others in use. Thus we find in this country gauges of 3 ft. 0 in., 3 ft. 6 in., 4 ft. 0 in., 4 ft. $8\frac{1}{2}$ in., and 5 ft. $2\frac{3}{16}$ in., while on the Continent the metre gauge is common.

The selection of the gauge is a matter for careful consideration. While a wide gauge enables large cars to be run, and therefore increases the passenger accommodation, a narrow gauge is often preferable, for the important reason that a double track can then be laid in many streets, where otherwise a single track would have to be used.

Influence of Gauge on Passenger Accommodation.—It is instructive to notice how the gauge influences the total width of the car body, and consequently the passenger accommodation. The usual arrangement, in this country, is to have two longitudinal seats inside the car, with a central gangway, and cross seats of the garden pattern outside, also with a gangway. The width of the car will therefore affect the inside gangway, but not the inside seating accommodation. With the 3 ft. 6 in. gauge the width of the gangway is as small as is desirable; with the 3 ft. 0 in. gauge it is uncomfortably narrow; with the 4 ft. gauge it is ample; while with the larger gauges there is room to spare.

The outside seats, being arranged across the car, are considerably affected by the gauge. The use of the 3 ft.

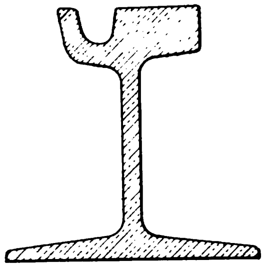
6 in. gauge allows three passengers to be accommodated in each row, the seats being usually for two passengers, and for one passenger, with a clear gangway of about 15 in. between. With the 3 ft. 0 in. gauge, room cannot be found for three seats in a row, without making the gangway too narrow. The 4 ft. 0 in. gauge cannot accommodate four passengers, except by doing the same thing, so seats are generally provided for three passengers, and the gangway is left wider. With the 4 ft. $8\frac{1}{2}$ in. gauge, room can be found for four seats in one row, and the 5 ft. $2\frac{3}{16}$ in. gauge can do no more.

Where open cars are in use, both the inside and the outside seats can be arranged across the car. In such cases the gauge affects both, because, with any given gauge, the width of the car body is limited. But, except for summer traffic, open cars are seldom used. For ordinary service, therefore, the choice would be between the 3 ft. 6 in. gauge, and the standard gauge of 4 ft. $8\frac{1}{2}$ in. Except for wider gangways the 4 ft. 0 in. gauge offers no advantage over the 3 ft. 6 in. gauge, while the 5 ft. $2\frac{3}{16}$ in. gauge is found only in the Emerald Isle.

Types of Rails.—Many types of rails have been designed and used, all having the same object in view, viz. that of providing a smooth-running surface for the car wheels, and a groove for receiving the wheel flanges. The greater the width of the groove, the less is it likely to become choked with dirt, and the smaller therefore will be the friction of the flanges. In America, where the tramway traffic is generally considered of more importance than the ordinary vehicular traffic, the groove is much wider, and is also formed in a different way to that allowed in this country, where a condition of laying tram-rails is that they shall not interfere with other traffic.

A comparison of Fig. 81, which shows the standard type of grooved girder rail in use here, with Fig. 82, which shows

Fig. 81.

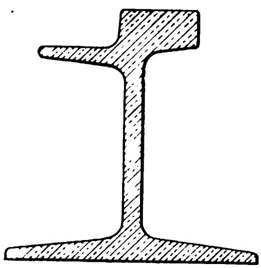


GROOVED GIRDER RAIL.

a type of step girder rail in common use in America, will illustrate this.

When step girder rails are used, the head of the rail

Fig. 82.



STEP GIRDER RAIL.

is sometimes kept above the surface of the road, in order to bring the step on the road level. In other cases, the head of the rail is on the road level, and the paving between the rails is slightly dipped at the sides.

The Girder Rail.—Tramway rails are now made entirely

of rolled steel, and the girder type of rail, as illustrated above, is practically universal, at any rate in this country, and for street tramways worked by electricity. They may be obtained of almost any variety of dimensions and weights, as the following table, compiled from the section sheets of Messrs. Dick, Kerr and Co., Ltd., will show.

TABLE 7.—DIMENSIONS OF STANDARD GIRDER RAILS.

Lbs. per Yard.	Depth.	Flange width.	Flange Thickness.		Face width.	Tread width.	Groove.		Web thickness.
			At Edge.	At Web.			Width.	Depth.	
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
81	6	6	$\frac{1}{4}$	$\frac{5}{8}$	$3\frac{5}{8}$	2	$1\frac{1}{8}$	1	$\frac{3}{8}$
82	6	6	$\frac{3}{8}$	$\frac{5}{8}$	$3\frac{1}{8}$	$1\frac{5}{8}$	$\frac{15}{16}$	1	$\frac{3}{8}$
83	$6\frac{1}{2}$	6	$\frac{5}{16}$	$\frac{9}{16}$	$3\frac{1}{8}$	$1\frac{5}{8}$	$1\frac{1}{16}$	$\frac{3}{4}$	$\frac{7}{16}$
83	$7\frac{1}{8}$	$5\frac{3}{4}$	$\frac{5}{16}$	$\frac{9}{16}$	$3\frac{7}{8}$	$1\frac{15}{16}$	$1\frac{1}{8}$	1	$\frac{3}{8}$
84	$6\frac{1}{2}$	$5\frac{1}{2}$	$\frac{5}{16}$	$\frac{1}{2}$	$3\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{3}{8}$
84	$7\frac{1}{8}$	$5\frac{1}{2}$	$\frac{5}{16}$	$\frac{1}{2}$	$3\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{1}{16}$	$\frac{13}{32}$
85	6	$4\frac{1}{2}$	$\frac{3}{8}$	$\frac{9}{16}$	$3\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{5}{16}$	$\frac{15}{16}$	$\frac{1}{2}$
85	7	$6\frac{1}{2}$	$\frac{1}{4}$	$\frac{9}{16}$	3	$1\frac{1}{2}$	1	$\frac{7}{8}$	$\frac{1}{2}$
86	7	6	$\frac{5}{16}$	$\frac{5}{8}$	$3\frac{1}{8}$	$1\frac{5}{8}$	$\frac{15}{16}$	1	$\frac{3}{8}$
87	$6\frac{1}{2}$	6	$\frac{5}{16}$	$\frac{1}{2}$	$3\frac{3}{8}$	$1\frac{3}{4}$	1	$\frac{7}{8}$	$\frac{1}{2}$
87	$6\frac{1}{2}$	6	$\frac{5}{16}$	$\frac{9}{16}$	$3\frac{3}{8}$	$1\frac{13}{16}$	1	$\frac{7}{8}$	$\frac{7}{16}$
87	$6\frac{1}{2}$	$6\frac{1}{2}$	$\frac{5}{16}$	$\frac{9}{16}$	$3\frac{1}{8}$	$1\frac{3}{4}$	1	$\frac{3}{4}$	$\frac{1}{2}$
90	$5\frac{7}{8}$	6	$\frac{3}{8}$	$\frac{11}{16}$	$3\frac{3}{4}$	2	$1\frac{1}{8}$	$1\frac{3}{16}$	$\frac{7}{16}$
90	6	$5\frac{1}{8}$	$\frac{3}{8}$	$\frac{3}{4}$	$4\frac{1}{8}$	$2\frac{3}{8}$	$1\frac{3}{16}$	1	$\frac{7}{16}$
90	6	7	$\frac{3}{8}$	$\frac{3}{4}$	3	$1\frac{5}{8}$	1	$\frac{3}{4}$	$\frac{7}{16}$
90	7	6	$\frac{5}{16}$	$\frac{9}{16}$	$3\frac{1}{4}$	$1\frac{5}{8}$	1	$\frac{3}{4}$	$\frac{7}{16}$
90	7	$6\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{8}$	$3\frac{1}{8}$	$1\frac{5}{8}$	$\frac{15}{16}$	$\frac{3}{4}$	$\frac{7}{16}$
90	7	7	$\frac{5}{16}$	$\frac{5}{8}$	3	$1\frac{9}{16}$	$\frac{7}{8}$	$\frac{11}{16}$	$\frac{3}{8}$
90	$7\frac{1}{8}$	7	$\frac{5}{16}$	$\frac{11}{16}$	$3\frac{1}{16}$	$1\frac{1}{2}$	$1\frac{1}{16}$	1	$\frac{7}{16}$
92	6	7	$\frac{3}{8}$	$\frac{11}{16}$	3	$1\frac{3}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{16}$
92	7	7	$\frac{1}{4}$	$\frac{5}{8}$	$3\frac{3}{4}$	$2\frac{1}{16}$	$1\frac{3}{16}$	1	$\frac{3}{8}$
95	$7\frac{1}{16}$	$6\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{8}$	$3\frac{5}{8}$	$1\frac{7}{8}$	$\frac{15}{16}$	$\frac{13}{16}$	$\frac{7}{16}$
97	7	7	$\frac{3}{8}$	$\frac{13}{16}$	3	$1\frac{1}{2}$	1	$1\frac{1}{8}$	$\frac{1}{2}$
98	7	7	$\frac{5}{16}$	$\frac{11}{16}$	3	$1\frac{7}{16}$	$\frac{15}{16}$	$\frac{7}{8}$	$\frac{1}{2}$
100	$6\frac{1}{8}$	7	$\frac{5}{16}$	$\frac{5}{8}$	$3\frac{3}{4}$	2	$1\frac{3}{16}$	$1\frac{3}{16}$	$\frac{1}{2}$
100	7	$7\frac{1}{16}$	$\frac{5}{16}$	$\frac{11}{16}$	$3\frac{1}{16}$	$1\frac{9}{16}$	$\frac{7}{16}$	$\frac{7}{8}$	$\frac{9}{16}$
100	$7\frac{1}{8}$	7	$\frac{1}{4}$	$\frac{3}{4}$	3	$1\frac{1}{2}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{1}{2}$
101	7	$6\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{8}$	$3\frac{5}{8}$	$1\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{16}$
101	$8\frac{1}{16}$	6	$\frac{3}{8}$	$\frac{5}{8}$	$3\frac{1}{4}$	$1\frac{5}{8}$	1	$\frac{3}{4}$	$\frac{1}{2}$
102	6	$7\frac{1}{8}$	$\frac{3}{8}$	$\frac{5}{8}$	$3\frac{1}{4}$	$1\frac{3}{4}$	$\frac{7}{8}$	$\frac{11}{16}$	$\frac{9}{16}$
103	$6\frac{1}{8}$	$6\frac{1}{2}$	$\frac{5}{16}$	$\frac{3}{4}$	$3\frac{1}{8}$	$1\frac{5}{8}$	1	$\frac{3}{4}$	$\frac{19}{32}$
106	$6\frac{1}{8}$	7	$\frac{5}{16}$	$\frac{3}{4}$	$3\frac{1}{8}$	$1\frac{1}{2}$	$1\frac{3}{16}$	$1\frac{1}{16}$	$\frac{5}{8}$

Weight of Rails.—Owing to the great weight of electric tramcars, a much stronger road is necessary, than will suffice for horse traction, and rails weighing less than 80 lbs. per yard are not satisfactory. In fact, the tendency is to use rails approaching 100 lbs. weight per yard, on all recent lines. The table, given above, shows what large variations are found in the dimensions of even heavy weight girder rails, while, if rails weighing less than 80 lbs. per yard had been included, the variation would have been still more marked. It seems impossible to avoid coming to the conclusion, that the differences are largely due to the personal fancies of the designer. Local conditions will govern the shape and dimensions of the rail to a certain extent, but there can be no need for such a variety as shown.

As the weight of the rail is largely determined by the weight of the vehicle it has to carry, so it would appear that a wide gauge line would need heavier rails than a narrow gauge one, for, on a wide gauge, the cars would necessarily be heavier, because of their greater width, and also because of the greater number of passengers carried.

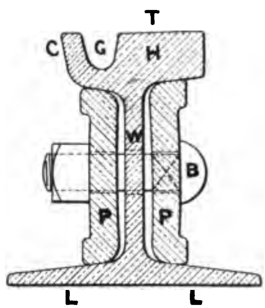
Rail Grooves.—The shape and dimensions of the rail groove have an important bearing on the easy running of the car. In order that the weight of the car may come entirely on the tread of the rail, the groove must be deep enough to permit the wheel flange to clear the bottom, even after considerable wear of the rail, and the wheel rim, has taken place. The width of the groove should be great enough to prevent easy clogging with dirt, and to allow freedom for the wheel flange, particularly on curves.* Step girder rails, as shown in Fig. 82, having what practically amounts to an exceedingly wide groove,

* See p. 238, Chap. VIII.

offer far less resistance to traction than grooved rails, because they are far less liable to obstruction from dirt. But they are not suitable for use in smoothly-paved streets, owing to their interference with ordinary traffic.

Driving tramcars by electricity, or by any self-contained power, introduces various conditions which are not felt when horses are used. In a horse car the wheels are simply trailers, but, in a mechanically-driven car, the wheels do the actual propelling. It is therefore essential that they should not slip, and that there should be no

Fig. 83.



CROSS-SECTION GIRDER RAIL AND FISH-PLATES.

tendency for the flanges to climb out of the grooves. It would be well if more attention were paid to increasing the area of contact between the wheel and the rails, by shaping the tread of the rail and the rim of the wheel, so that the latter has a bearing entirely over its width.

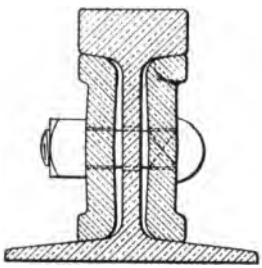
In Fig. 83 is shown a cross-section of a modern grooved girder rail and fish-plates, at a joint, with the various parts lettered for reference.

References :—T = Tread.
G = Groove.

C = Lip or Guard.
H = Head.
W = Web.
L = Flange.
P = Fish-plate.
B = Bolt.

T-headed Rails.—Where the track can be protected, T-headed girder rails, as in Fig. 84, for bolting down to wooden sleepers, or the ordinary bull-nosed railway rail, for use with chairs, are generally preferable. The great advantage

Fig. 84.



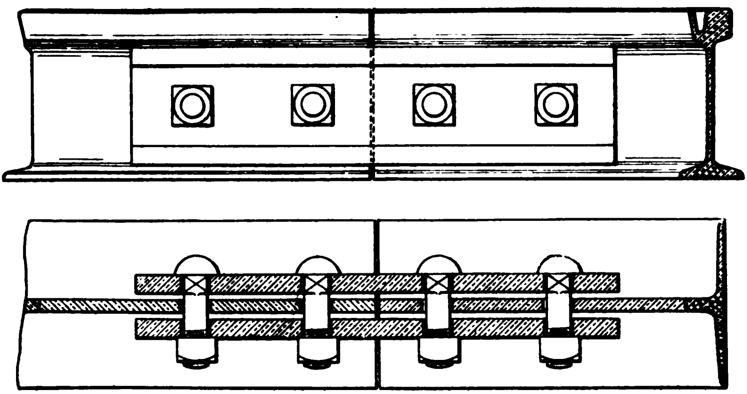
T-HEADED GIRDER RAIL.

is the absence of the groove, and hence lessened tractive resistance. The use of the T-rail is common in America, even for ordinary street work, the necessary space for the rim of the wheel being formed by dipping the paving on either side, or by the use of special paving blocks.

Rail Joints.—Rails are supplied in lengths varying from 30 ft. to 60 ft., and are usually jointed by means of fish-plates, as shown in section in Fig. 83, and in side elevation and plan in Fig. 85. The fish-plates are made of steel, and should be so shaped as to have as large and equal a bearing as possible under the head, and upon the flange, of

the rail. The bolts generally pass clear through the fish-plates and the web of the rail, and are secured by means of external nuts. In some instances, however, the fish-plates on one side have been tapped, and the bolts secured into them without the use of nuts. This arrangement makes the bolts very difficult to remove, in case of breakage. In order to prevent the fish-plates buckling under the strain of the bolts, they are made convex, while, for very deep rails, it is sometimes necessary to use a double

Fig. 85.



ELEVATION AND SECTIONAL PLAN OF RAIL JOINT.

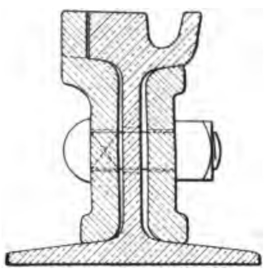
line of bolts, and an internal rib on the fish-plates between them.

When rails are laid in the open (*i.e.* not buried), it is necessary to allow a small space between the ends, in order to provide for expansion during hot weather. This causes hammering whenever the car wheel passes, but the nuts and fastenings are readily got at for adjustment, in the event of their becoming loose. When laid in macadamized or paved streets, and entirely buried, the fish-plates and

nuts are inaccessible, and the rails-ends should be practically butted together, especially if laid during hot weather. Experience has shown that, with buried rails, no trouble need be feared from expansion or contraction in the direction of their length, what movement there is taking place in the thickness. Buried rails are not so subject to changes of temperature as rails which are entirely open.

In order to avoid the hammering effect of the car wheels, owing to the space between the rail-ends, a kind of overlapping joint has been introduced, as shown in Fig. 86. A

Fig. 86.



CROSS SECTION OVERLAPPING RAIL JOINT.

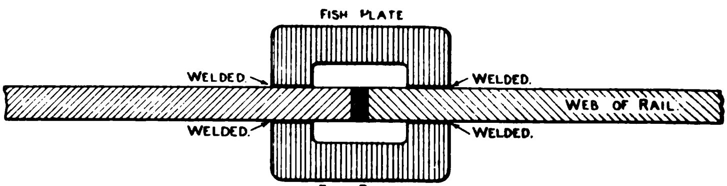
portion of the head of each rail is cut away at the ends, and the outer fish-plate is brought up to the top, forming a part of the tread. Such a joint would be satisfactory, only when the wheel rim had a full bearing over the tread of the rail.

One way to lessen the troubles caused by rail joints is to minimize their number, by always using the longest rails which can be procured. Rails 45 ft. and 60 ft. in length are now obtainable, and, although heavier and more troublesome to handle than shorter lengths, the advantages gained in the reduction of the number of joints is more than worth the extra labour.

Continuous Rails.—Unless rail-joints are very carefully made, they are always liable to become a source of trouble. The heavy traffic often loosens the fish-plates, with the result that the rail-ends become more or less free, and serious hammering takes place. A perfect joint should never move when a car passes, and practically the only way to obtain this perfection is to adopt continuous rails.

There are two methods by which rails may be jointed into continuous lengths, when in position, one being electric welding, and the other cast welding.

Fig. 87.

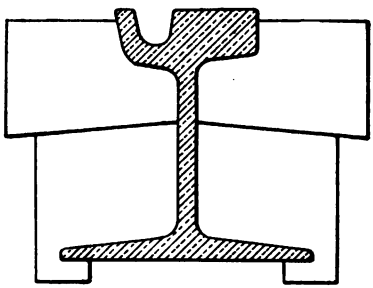


ELECTRICALLY-WELDED RAIL JOINT, WITH FISH-PLATES.

Electrically-welded Rails.—The electric welding process was introduced in the United States about the year 1893, and, since then, a considerable mileage of track has been dealt with. Two types of joints have been tried, one employing fish-plates, and the other special lugs. In preparing for the joint, an emery wheel, driven by a portable motor supplied with current from the trolley wire, is used to clean the surfaces, and, when a space exists, a thin piece of steel is driven between the ends of the rails. The fish-plates are of special shape, as will be seen from Fig. 87, which shows a sectional plan, and the weld takes place between the fish-plates and the rail, rather than between the rails themselves.

The use of lugs, however, does away with the necessity of fish-plates, and a weld is obtained between the rail-ends. Four steel lugs, shaped as in Fig. 88, are used, the two lower lugs being first jointed, and then the two upper ones. In either case special clamps are employed to hold the fish-plates or lugs in position, and so that pressure can be applied when the welding temperature is reached. It is found that molten steel, from the inner faces of the lugs,

Fig. 88.



ELECTRICALLY-WELDED RAIL JOINT, WITH LUGS.

can be forced into the space between the rail-ends, and, by the use of a hammer, the face of the rail can be smoothed.

Current for the welding process is obtained from the trolley wire in the following manner. A 500 volt direct current motor drives an alternator which feeds the primary side of the welding transformer. The secondary side delivers an alternating current, at about 3 or 4 volts pressure, to the welding contacts, and a current of about 40,000 ampères is used, at that pressure, for several minutes. The motor-alternator is carried upon a van, running on the rails in advance of the joint, and driven by motors in the same way as an ordinary tramcar. The

welding transformer and clamps are suspended from the rear of the van. The joint is made at the back, in order that the van may not pass over a newly-made joint, when it is run forward for the next.

Electrically-welded joints appear to have given good results whenever the welding has been properly done. The engineer of the Citizens' Railway Co., St. Louis, U.S.A., states that, from his experience, about 4·5% of the joints have broken in four years, and that, in every case, a broken joint has shown an imperfect weld. The difficulty of ensuring a good weld, the expensive outfit required, and the impossibility, in the majority of cases (particularly on new lines), of obtaining the necessary supply of current, have all helped to prevent the extended use of this process.

Cast-welded Rails.—A more promising method is that of forming the joint by means of a cast weld. It consists in casting an iron sleeve around the sides and bottom of the rail joint. The rails are laid in the usual way, with the ends butting together, but without the use of fish-plates. If old rails are to be jointed, the fish-plates are removed, and any openings between the ends are filled up by a thin section of the rail. The sides and bottom surfaces of the rail-ends are thoroughly cleaned, by means of a portable emery wheel or sand-blast, in a similar way to that used when preparing for an electric weld, and cast-iron moulds are then clamped in position. The moulds are in halves, one for each side of the rail, and are coated on the inside with plumbago, to prevent the molten metal from sticking to them. Great care is taken to ensure that the rail-ends are exactly in line, and strong clamps are used to keep them in position, while the joint is being made.

The iron used for the joint is a good soft grey pig-iron, and it is melted in a portable furnace, consisting of cupola, fan, engine and boiler, mounted on a truck, and drawn by horses. A ladle, holding enough metal for one joint, is used for pouring, and as many as 100 joints can be made with one heating, if proper arrangement be made, the cupola, etc., being taken from joint to joint as required.

The moulds should be well heated before being applied to the rail-ends, in order to prevent too sudden cooling of

Fig. 89.

SECTION THROUGH CAST WELDED RAIL JOINT.

the joint. The contraction of the outside of the joint, in cooling, applies a tremendous pressure to the more molten metal inside, and forces it into intimate contact with the rail. The joint is generally about 14 inches long, taking in two bolt-holes on each side, and the molten iron fills up these, as well as any space between the ends of the rails, thus forming a sound mechanical joint. The weight of iron required for each joint varies with the size of the rail, from about 70 lbs. to 140 lbs., and the cross-section of the joint from about 39 sq. in. to 60 sq. in.

Fig. 89 represents a cast weld joint after it has been

cut in half, and it shows what intimate contact exists between the casting and the rail. In many cases it is found that parts of the rail are actually melted, and combined with the cast-iron.

In calculating the stresses upon the joints in continuous rails, due to changes of temperature, a range of 75° Fahr. may be taken as the maximum variation, above or below the temperature at which the joint was made. Steel rails will expand or contract about 0·0000065 of their length for each degree Fahr., or 0·000487 of their length for 75°. Under a stress of 1,000 lbs. per sq. in., a steel rail will expand about 0.00003 of its length, so that an expansion of 0·000487 of its length represents a stress of about 16,200 lbs. per sq. in.

Tests taken on the cast welded joint of a 6-in. girder rail, weighing about 75 lbs. per yard, have shown an average breaking strength of 197,000 lbs. This is quite sufficient to meet the stresses due to expansion, since a stress of 16,200 lbs. per sq. in. on a 6-in. rail, is equal to a total stress of only about 121,500 lbs.

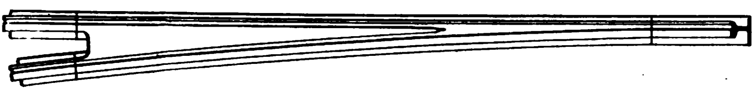
It is found advisable, in order to prevent too severe expansion and contraction during jointing, to cast first every other joint, and to allow these to become quite cool, before proceeding with the intermediate ones.

The cast welded joint has been adopted in this country on both the Coventry and Norwich tramways, and so far with very satisfactory results. In the United States it has been largely used, and it appears to be a method well worthy of the consideration of tramway engineers. The few cases of broken joints which have been noticed have been due either to defective castings, or to improper support under the joints.

Points and Crossings.—With only a single track, and

only a single car in use, there is no necessity for anything else, except the plain pair of rails, from one end of the route to the other. But, as soon as more than one car is run, "turn outs" or passing places must be added to the single track at intervals on the route, so that the cars may pass each other, or else there must be generally a double track throughout. With a double track, cross-over roads, or loops, at both ends are necessary, in order that cars, travelling in one direction, may always keep to the same pair of rails. In either case it introduces special work, in the shape of curves, points, and crossings, and these are used whenever cars have to be transferred from one set of rails to the other.

Fig. 90.



PLAN OF OPEN POINT.

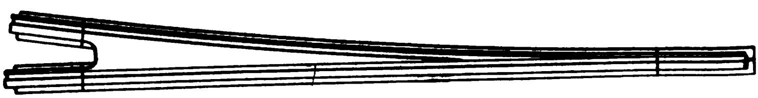
Points are of three kinds, viz.: open or neutral points, fixed points, and movable points, and are called, in addition, "facing" or "leading" points when the track diverges, and "trailing" points when the tracks converge, in front of the running car. As there are two rails to each single track, points must be used in pairs, although the pair need not always consist of two points of the same kind.

An open point is shown in plan in Fig. 90. The tapered tongue is fixed in the centre of the divided grooves, and the entrance to the groove on each side of the tongue is the same, so that, when used as a facing point, there is no tendency for the car wheel to take either track, in

preference to the other. Open facing points, in pairs, are not desirable, even on horse lines, where the car can generally be induced to take one track or the other, by means of a side pull, while on electric lines they should never be used. Open points are only suitable for use either as trailing points, or as one of a pair of facing points, the other being either a fixed or a movable point.

Fixed points are similar to open points, in that the tongue is not movable, but the level of the right-hand groove is raised at its entrance, thus directing the wheel of the car into the left-hand track. On horse lines they are fairly successful, as they can always be assisted by a side pull, but they are not desirable on electric lines.

Fig. 91.



PLAN OF FIXED POINT.

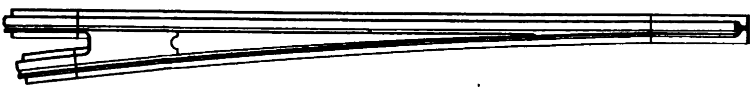
When running over a trailing fixed point, the car wheel rides on its flange for a few inches, and then drops to its face as it passes the point. This causes a nasty jerk, which is most detrimental to the gear of electric cars. Fig. 91 shows a fixed point in plan. They may be used either in pairs, or with an open point.

Movable points are, as the name indicates, points in which the tongue can be moved from one side to the other, thus completely closing one track, and leaving the other fully open. The tongue is either moved by a hand lever or by a short bar, which may be carried on the car, or is controlled by means of a spring. The latter form is called a "spring" point. Points moved by hand are used,

when it is desirable to turn a car into either of two tracks, as, for example, at the junction of two roads.

Spring joints are only employed on turn-outs, or cross-over roads, to keep one track permanently open for cars travelling in one direction, cars coming in the other direction, on the same track, having to push the tongue

Fig. 92.

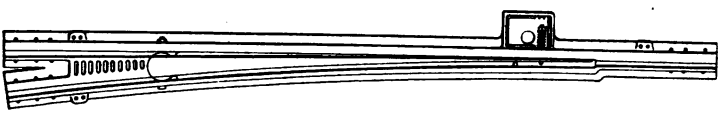


PLAN OF HAND-WORKED MOVABLE POINT.

over against the force of the spring, by the wedging action of the wheel flanges. When the car has passed, the spring at once restores the tongue to its former position.

Fig. 92 shows a hand-worked movable point in plan and elevation, and Fig. 93 a spring point.

Fig. 93.

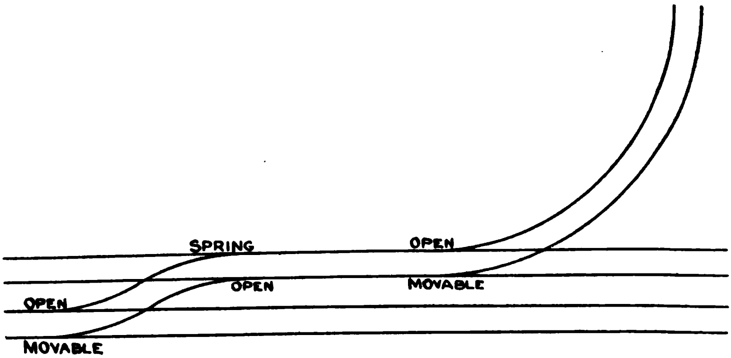


PLAN OF SPRING POINT.

The tongue is worked upon a strong steel pin, held in place by a cotter on the underside, and a hand-box for cleaning-out purposes should always be provided. Movable points can either be used in pairs, or in conjunction with an open point. Spring points are equivalent to fixed points, and are generally much superior to them, by reason of the smoother running obtained, but they

require constant attention and cleaning in order to ensure their proper working. They should always be placed so that they are forced open by the inside of the wheel flange, and so that they have not to carry any of the

Fig. 94.

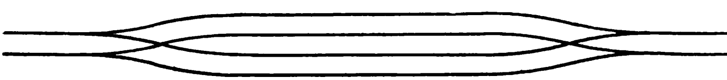


POINTS AT INTERMEDIATE TERMINUS.

weight of the car while being moved. Fig. 94 shows an arrangement of movable, spring, and open points at an intermediate terminus on a main route.

The three following figures show examples of turn-outs

Fig. 95.



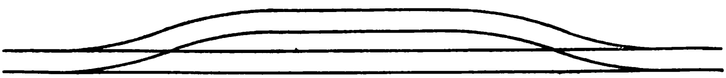
CENTRE TURN-OUT.

for a single track. In Fig. 95 the two tracks are divided equally on each side of the centre line, a form of turn-out which is really only suited for horse-traction. A moving spring point at each end would be found necessary

to ensure good working, as with a pair of open points it would be impossible to make the car take either road properly without a heavy side pull.

Fig. 96 shows the turn-out placed at the side of the

Fig. 96.

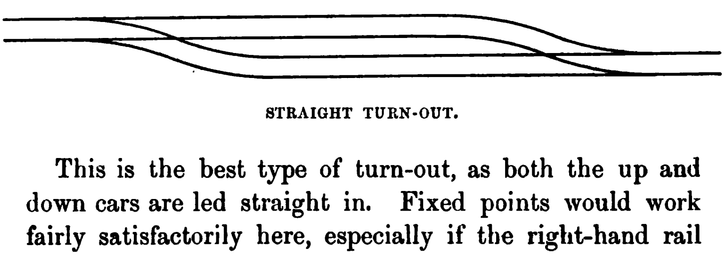


SIDE TURN-OUT.

main track. Here the entrance is much easier for a car travelling in the left-hand direction, than for one coming the other way, because, in the former case, the track leads straight in. A fixed point would answer at the right-hand entrance, but, at the left hand, a moving spring point would be necessary.

A turn-out, in which the entrance from either end is the same, is shown in Fig. 97.

Fig. 97.



STRAIGHT TURN-OUT.

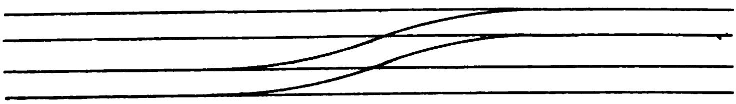
This is the best type of turn-out, as both the up and down cars are led straight in. Fixed points would work fairly satisfactorily here, especially if the right-hand rail at each end be slightly raised at the point, thus making the car keep over to the left-hand track. But spring points would be far preferable.

Fig. 98 is an example of a cross-over for a double track. This may be either at an intermediate spot on the

route, and intended for use only in cases of emergency, to pass cars from either track to the other, or at the terminus, to transfer all cars.

In laying down lines for electric traction, on which

Fig. 98.

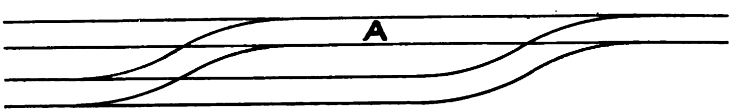


CROSS-OVER ROAD.

trailer cars are intended to be used, provision must be made at the termini, not only for transferring the motor and trailer cars to the return track, but also for allowing the motor-car to change its position to the other end of the trailer.

The ordinary method is to provide a second cross-over road, as shown in Fig. 99. The cars arrive on the upper lines, the trailer is detached at A, the motor-car goes

Fig. 99.



CROSS-OVER FOR TRAILER CARS.

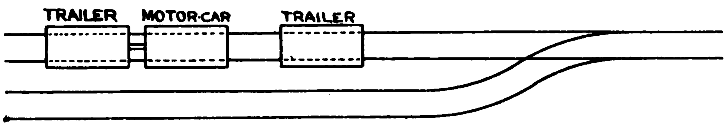
forward, returns on the other track, and crosses over to the first track to be attached to the front of the trailer. The two cars then cross over to the second track for the return journey.

This arrangement not only requires a second cross-over road, but also entails at least three separate movements of the motor car, with (on the overhead system) three trolley

changes, before the cars are in their correct position. This means considerable loss of time.

A much simpler method is to employ a spare trailer at each terminus, in the manner shown in Fig. 100. The motor car stops when it reaches the standing trailer. It is then uncoupled from its own trailer, and coupled to the standing trailer, which it pushes forward to the other track, leaving its own trailer standing ready for the next incoming car. The two cars are then ready for the return journey, after only one movement of the motor car, only one trolley change, and without a second cross-over road.

Fig. 100.



USE OF SPARE TRAILER CAR.

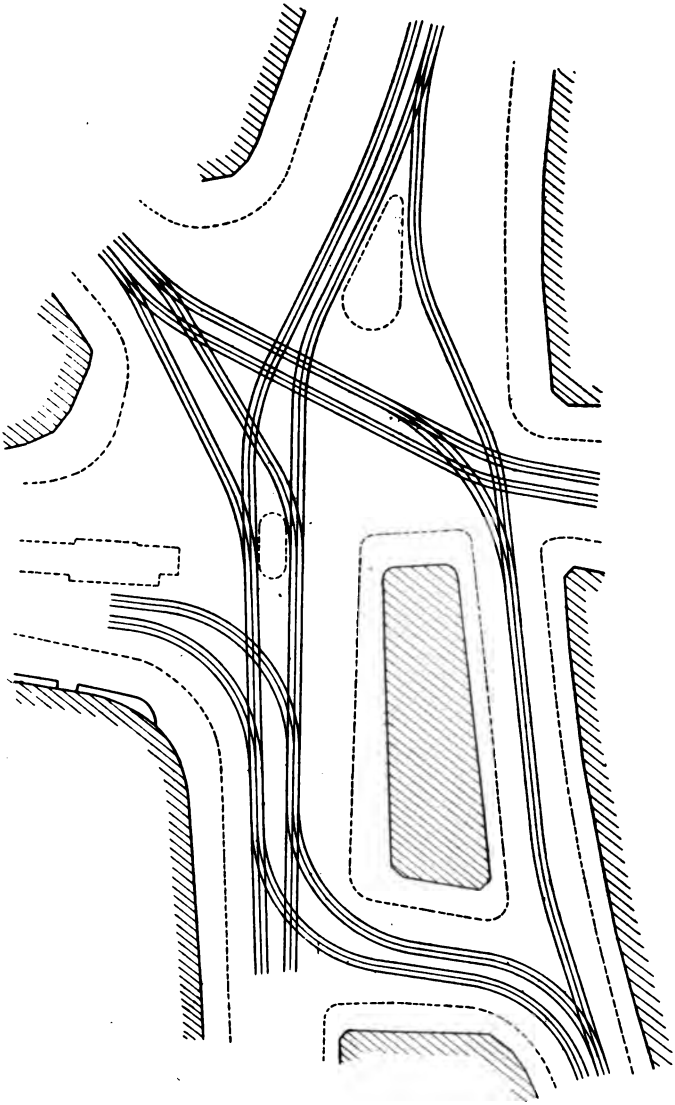
The standing trailer car may conveniently be made use of as a waiting-room for intending passengers.

In Fig. 101 is shown the complicated tracks at the Elephant and Castle junctions of the L.C.C. tramways.

In order that cars may pass from one track to another, without strain or jerk, points should be made as long, and with as small an angle, as possible, and the rails should be laid with long and easy curves. It is a common fault in tramway construction, that points, curves, and cross-over roads are too abrupt, thus not only jerking and straining the cars passing over them, but also increasing the liability to derailment. The tongues and grooves of points should always be curved to suit the lead-off of the track.

Crossings (or frogs) can be obtained of any angle of

Fig. 101.

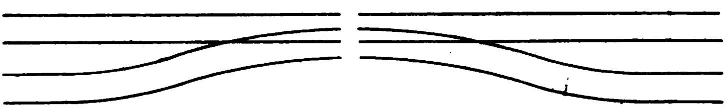


POINTS AND CROSSINGS AT "ELEPHANT AND CASTLE."

intersection which may be required. They should either be kept extremely short, or should be curved to suit the sweep of the cross-over road.

Points and crossings are often made of annealed cast steel, and at times are built up from pieces of girder rail. The ordinary way of jointing these is by the use of rivets, or bolts and nuts. But a much superior method has recently been introduced, whereby molten manganese steel is run around the joints, and through holes in the rails, making a kind of "cast weld" joint. The contraction of the molten metal firmly holds all the parts in position.

Fig. 102.



INTERLACING LINES.

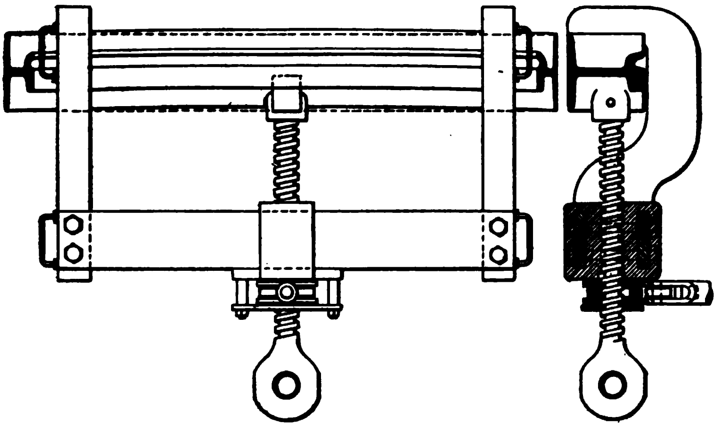
Certain portions of points and crossings are subject to excessive wear, since they have to carry the entire traffic of both lines, and often upon a much reduced bearing surface. The use of parts of girder rails for this work is good, since it provides a metal equal to the rail itself, but what is really wanted is a metal harder than the rail, in order to allow for the additional wear.

It is claimed that "manganese steel" fully meets all the requirements, as it is very malleable, and also extremely hard. Points and crossings made from this metal should therefore be very suitable for heavy lines.

Interlacing Lines.—It is always advisable to have a double track throughout a system, in order both that the

cars may not have to wait for each other at passing places, and also to avoid the use of points, which are always liable to give trouble. But, owing to the narrowness of portions of streets, and to other local circumstances, it is not always practicable to lay double lines, so that cars can pass each other at any point. The usual practice, in these cases, is to converge the two tracks into a single one, until the

Fig. 103.



"JIM CROW," OR RAIL BENDER.

width of the roadway is again sufficient. This necessitates the use of points at either end.

A much better way, although more expensive in first cost, is to continue the double track by means of interlacing lines, as in Fig. 102. Although cars cannot pass each other on the interlaced section, yet each track is continuous without interruption, and no points are required. The interlaced lines will also last longer than the single track, as they are exposed to only one-half the wear.

Curves.—Any deviation from a straight line introduces a curve, of one radius or another. The deviation may be so slight, that it is only noticed by sighting along the track, or it may be so great as to constitute a very sharp curve. Rails will readily "give" a few inches, when jointed in long lengths, but, to form an appreciable curve, each length must be bent into correct shape before being laid. Rail-benders, or "Jim Crows," are used for this work, and an illustration of an improved form is shown in Fig. 103.

Tramway curves are always compared by their radii, and, as there are two rails to each track, the mean radius of the curves of the two rails is always spoken of as the radius of the curve.

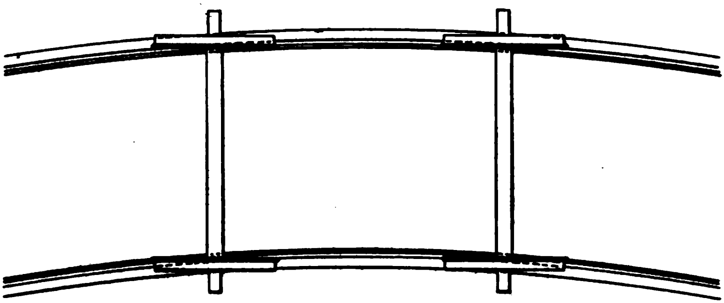
Curves should, in all cases, be made with as large a mean radius as possible, for the tractive resistance increases very considerably as the radius is reduced. Great care should be taken in setting curves out, as the rails have to be relied upon entirely to guide the car, no side pull, such as can be obtained with horses, being possible with self-propelled cars. The greater speed of electric cars also necessitates easier curves. Practice has shown that the simple circular curves, common on horse lines, are not suitable for high-speed electric cars, and that the most satisfactory are spiral transition curves, or curves formed by a spiral, with constantly decreasing radii each way, to the centre of the curve.

The length of the wheel-base is largely controlled by the minimum mean radius of the sharpest curve upon the route. Mr. Dawson gives a wheel-base of 6 ft. as the maximum for a curve of 25 ft. minimum mean radius, but a wheel-base of 5 ft. 6 in., for a curve of 30 ft. minimum mean radius, will be found quite large enough for satisfactory running.

It is in going round curves that the benefits of a wider grooved rail are particularly felt, for the wheel-flange tends to set itself across the groove, by an amount depending upon the length of the wheel-base, and the radius of the curve. This is clearly indicated in Fig. 104, which also shows that the gauge of the track at a curve should be slightly *less* than on the straight, since the true gauge is required along the wheel-axle, and not on a radial line.

In laying double tracks round a curve, it is of the utmost importance that the passing of the cars should be

Fig. 104.



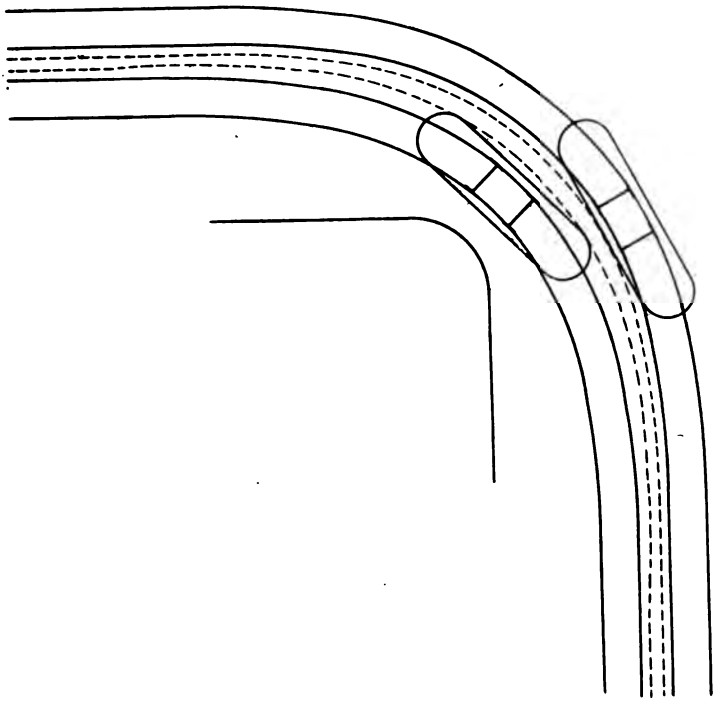
POSITION OF WHEELS ON CURVE.

considered. While it is always advisable to prohibit passing on a curve, on account of the greater liability to accident at these places, yet provision should be made that cars may readily pass if required. The greater length of electric cars, and the comparatively short wheel-base, make the ends of the cars overhang the track considerably, when going round a sharp curve. Consequently, the centres of the two tracks must be set farther apart, in order that the cars may clear each other. The best way is to make a plan of the curves, as in Fig. 105, and, with a cardboard or other model of the car, to plot out the curves of the ends

of the cars as they sweep round. The correct centres may then be easily ascertained.

The outer rail of a curve should always be slightly elevated, so as to make the car lean in the natural way,

Fig. 105.



POSITIONS OF CARS ON CURVES.

when passing round it. Owing to the nature of the roadway, this is not always practicable, as, for example, on a curve turning out of a continuous down grade into a side street. Here the natural fall of the roadway would lower the outer rail instead of raising it, and the amount of

banking allowed would probably hardly bring the rails level. In passing over such curves, it is necessary to exercise great care, and to run very slowly, as there is always a tendency for the car to leave the track, particularly when running at any speed. The correct elevation, for the outer rail of a curve, may be obtained from the following formula, viz.—

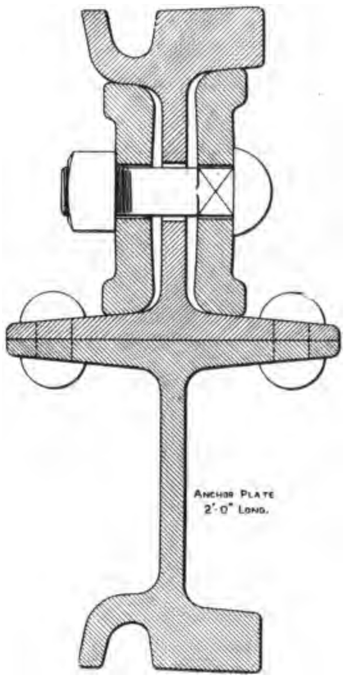
$$\text{Elevation of outer rail in inches} = N \times \frac{M^2}{1{\cdot}25\, C} \quad (11)$$

Where N = Width of gauge in feet.
M = Speed of car in miles per hour.
C = Radius of curve in feet.

Laying Rails.—The best tracks are now always formed by laying wide-flanged girder rails upon a bed of concrete, varying from 6 in. to 12 in. in thickness. Tie-rods are fixed at intervals between the rails, in order to preserve the gauge, and the space between and outside the rails is filled up by ordinary paving blocks. It is usual for the tramway authorities to maintain the surface of the roadway both between the tracks, and for a distance of 18 in. outside the tracks. In some cases, longitudinal wooden sleepers are laid in the concrete to carry the rails, and sometimes iron chairs or sole-plates are used at the rail-joints, in addition to the fish-plates. These form an excellent support, when bolted to the flanges, and, when incorporated with the fish-plate, they are particularly good. A very simple, but most effective, sole-plate may be easily made from pieces of old girder rail, about 3 ft. long, turned upside down, and bolted, or rivetted, flange to flange, on the underside of the rail-joint, as shown in Fig. 106. This not only acts as a support to the joint, but also serves as "an anchor" to the track, by preventing "creeping" of the rails on hilly routes.

The cost of laying a track of course varies with the method of construction, with the cost of labour in the district, and with the market value of steel rails. Taking rails weighing 100 lbs. per yard, and costing £7 per ton,

Fig. 106.



TRACK RAIL JOINT WITH SOLE-PLATE.

a double track, laid upon 8 inches of concrete, will cost between £8,000 and £10,000 per mile, including the repaving.

The Rail as a Conductor.—The use of electricity as a motive power, necessitates the provision of a closed circuit

for the passage of the current. When the supply of energy is carried upon the cars, in the shape of accumulators, the circuit is purely a local one, and presents no unusual features. But, when power is supplied to the moving cars from a fixed generating station, connection must be made by each car with two conductors, one acting as the "lead" and the other as the "return." While both overhead and underground wires are used for the former, the latter is often provided by the rails themselves, contact being made by the wheels.

In order to confine the return circuit to the rails, it is necessary that the difference of potential, between the extreme ends of the track and the end nearest to the generating station, when maximum current is passing, should be kept very low. The Board of Trade has fixed the maximum limit at seven volts,* and a continuous record has to be kept to show that this limit is not exceeded. The earth, being more or less a conductor, practically connects all buried metal in the vicinity of the tramways to the rails, so that, unless great care be taken, the return current leaks out from the rails, and flows back through the medium of any water, gas, or other metal pipes, which may be lying in the neighbourhood of the track.

The mere passage of the current through these pipes does no harm, but, at all points where the current leaves the pipes, corrosion takes place by reason of electrolytic action. The number of places at which the current flows into or out of the rails or adjacent pipes, is entirely a question of relative resistances (or of conductivities), between the various paths open to the current, and, at each place of leaving, corrosion goes on. The only way to pre-

* See "Board of Trade Regulations" in Appendix.

vent leakage currents, is to make the proper path of so low a resistance, that the difference of potential between any two points is at all times exceedingly small.

The resistance of steel rails varies inversely with their cross sectional area, and, to some extent, with the character of the steel. An average value may be obtained from the following, viz.—

$$\text{Resistance of single rail in ohms per mile} = \frac{2 \cdot 5}{\text{Weight in lbs. per yard.}} \quad (12)$$

Or, as the weight in lbs. per yard = the cross sectional area in sq. in. × 10,

$$\text{Resistance of single rail in ohms per mile} = \frac{0 \cdot 25}{\text{Cross sectional area in sq. in.}} \quad (13)$$

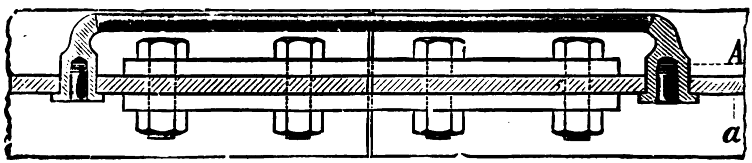
For the two rails of a single track, the above values would, of course, be divided by 2, and, for the four rails of a double track, by 4, since they would follow the laws of parallel conductors. If rails could be obtained and used in a continuous length, the total resistance of a track would be as given above. But, since joints are necessary, their resistance also must be taken into account.

Bonding.—The electrical resistance of an ordinary rail joint is exceedingly high, principally on account of the dirty surfaces of the rails and fish-plates. If these were carefully cleaned before being fixed, so that actual metal-to-metal contact were made, the resistance could be brought down to a very negligible amount. Such a state of things, however, would not last, because of the rapid rusting of the surfaces, and the loosening of the contacts caused by the heavy traffic passing over the joint. It is, therefore, necessary to supplement the mechanical coupling of the fish-plates by permanent electrical connections. Such connections are called "bonds."

Various types of bonds have been tried, some only to be abandoned after a short service, while others have proved more successful. The requirements of a good bond are:—(1) large contact surface with rail, (2) perfect freedom from loosening, (3) flexibility, (4) high conductivity, (5) ease of fixing, (6) moderate cost. These requirements are more or less met in the varieties of bonds described below.

The Chicago Bond.—One of the best known is called the "Chicago" bond, and is illustrated in Fig. 107. It consists of a solid rod of rolled copper, with a thimble-shaped terminal at each end. These are bent round at

Fig. 107.



CHICAGO RAIL BOND.

right angles, and inserted into holes drilled through the webs of the rails. The ends of the terminals have cross slits, and these are clinched over on the rail. A steel pin is then driven into each terminal, thus expanding it, and wedging it into solid contact with the surface of the hole in the rail.

The success of a joint of this nature, made between two dissimilar metals, depends upon the perfect cleanliness of the contact surfaces, and the maintenance of this condition. The latter is secured by means of the expanding action of the steel pin, as it makes a solid joint from which all air and moisture are excluded. The holes through the web of the rail may be drilled at any

time previous to the bonding, some $\frac{1}{8}$ in. less in diameter than the terminal of the bond. Immediately before the insertion of the bond a steel drift is forced through the hole, enlarging it to slightly less than the diameter of the terminal, and leaving the metal perfectly bright. The bond terminal is at once driven in, and, being slightly larger than the hole, the copper is scraped bright. The steel pin is then inserted and swells out the terminal, wedging the whole up tight.

The holes in the web of the rail should be at least a clear 2 in. from the fish-plates, and the completed bond should be well coated with preservative compound. Chicago bonds are made in the following sizes, and of lengths varying from 20 in. to 150 in., although the usual length of the bond is 30 in.

TABLE 8.—DIMENSIONS OF CHICAGO RAIL BONDS.

Size of Bond B. & S. Gauge.	Dia. of Bond in inches.	Gross Sectl. Area of Bond.	Dia. of Bond Terminal.	Dia. of Hole in Terminal.	Dia. of Steel Pin.
0	0·325	0·083	$\frac{1}{2}$ inch	$\frac{1}{4}$ inch	$\frac{5}{16}$ inch
00	0·365	0·104	$\frac{5}{8}$,,	$\frac{5}{16}$,,	$\frac{3}{8}$,,
000	0·410	0·132	$\frac{3}{4}$,,	$\frac{3}{8}$,,	$\frac{7}{16}$,,
0000	0·460	0·166	$\frac{7}{8}$,,	$\frac{7}{16}$,,	$\frac{1}{2}$,,

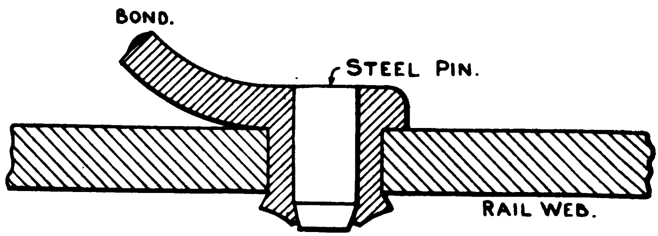
Owing to the size of its terminals, this bond has a large contact surface inside the web of the rail. It can be readily fixed, either to new rails when being laid or to an existing track. When the latter, the road must be opened on each side of the rail, as the bond is driven into place from one side, and the steel pin from the other.

In the case of points, which are usually of a box section, and also in many cases with crossings, it will be found necessary to secure these bonds to them before they are laid in place, as otherwise it will be impossible to

insert the steel pin properly from the inside. This, and the fact that both sides of the rail must be exposed to fix the Chicago bond, has led to the design of bonds in which the steel pin is inserted from the same side of the rail as the bond itself, so that the road need only be opened on one side.

The Neptune Bond.—The "Neptune" bond is similar to the Chicago bond in every respect, except that both the bond and the pin are placed in position from the same side of the rail. By making the hole in the bond terminal of a smaller diameter on the far side, the driving in

Fig. 108.



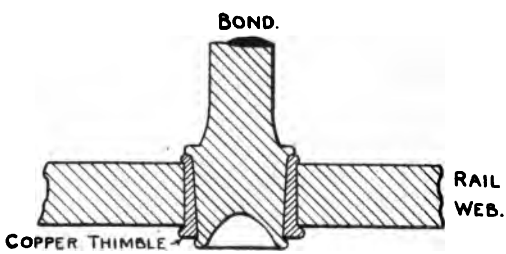
CROWN RAIL BOND.

of the pin opens out the end of the terminal, and effectually clinches it in place. These bonds can be obtained of the same dimensions as the Chicago bonds.

The Crown Bond.—A bond, practically identical with the above in the method of fixing, is manufactured under the name of the "Crown" bond. It is made in two forms, one a solid bond, and the other a flexible bond. The solid bond is long enough to span the fish-plate. The flexible bond is of two sizes, one being short enough to fix under the fish-plate, and the other a longer pattern for spanning the fish-plate. In the flexible bond the stranded

copper is welded into solid ends, thus forming a perfectly homogeneous mass of copper. The "Crown" bond is fixed in the same way as the "Neptune" bond, and Fig. 108 shows a section of the bond terminal in the rail. The chief merits of the flexible bond are, that it is easy of application, being readily adjusted to the position of the holes, and that it provides for all expansion and contraction. In a later type this bond is made with a solid head, which is pressed into place by a hydraulic rivetter. This is, perhaps, the best of all the copper bonds.

Fig. 109.



COLUMBIA RAIL BOND.

The Columbia Bond.—The "Columbia" bond, while relying upon contact made with the sides of a hole through the web of the rail, similar to all the bonds above described, is made of copper throughout, no steel pin being used. It has, instead, two loose copper thimbles. As will be seen from Fig. 109, the end of the bond has a truncated cone head. The inside of the loose thimble is tapered to fit the head of the bond, while the outside is tapered slightly in the opposite direction. In fixing the bonds, the cone-shaped heads are placed in the holes in the rails from the one side, and the thimbles are slipped

over them from the other. A portable hand-press is then applied, and the cone and thimble are tightly wedged together, contact being made at the same time with rail.

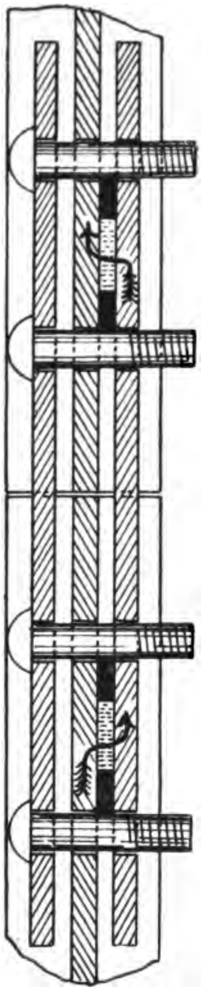


Fig. 110. EDISON-BROWN PLASTIC RAIL BOND.

It is claimed that the head and the thimble, being of the same metal, become practically one, and that the process of pressing is superior to that of driving in by hammer. The area of contact with the rail is greater than with the "Chicago" or "Crown" bonds, on account of the greater diameter of the thimbles, but against this must be set the fact, that while the former bonds make direct contact with the rail, the "Columbia" bond has first to make contact with the thimbles, and then with the rail.

The Edison-Brown Bond.—One of the most interesting bonds, is that known as the "Edison-Brown" plastic bond. In this bond there is no drilling of holes, the fish-plates themselves being used, both as the mechanical and the electrical joint between the rails. In a more recent type, flat copper straps are placed between the fish-plate and the rail, and are used, instead of the fish-plates, to carry the current. The bond consists of a

plastic metallic composition, in an elastic cork case, two being used at each joint, one between the web of each rail and the fish-plate, as shown in Fig. 110. The current passes from one rail through the first bond to the fish-plate, and then, from the fish-plate, through the second bond to the next rail.

In fixing this bond, contact spots about 2 in. in diameter, on the rails and fish-plates, are cleared of scale and rust, a very flat-ended drill with a guiding steel template being used. The contact spots are then wetted with water, and, while wet, are rubbed over with a piece of solid alloy, until the surfaces are silvered. Water is again applied. The cork cases for holding the plastic metal are then gently heated, until the black coating, with which they are treated, has softened. They are then pressed against the rails until they stick, care being taken that they are properly centered with the cleaned contact spots. The plastic compound is supplied in small wooden boxes, each holding just enough for one contact, so that each rail-joint requires two boxes. For heavy rails an amalgamated spring washer is supplied with the compound in each box. The cork cases being in place, the plastic metal and the spring washers are placed in the holes, the fish-plate is brought into position, and the nuts tightened up evenly. Spring washers are recommended for the nuts nearer the bonds.

It is claimed that the conductivity of a bond, made in this way, is practically equal to that of the rail itself, and that, when properly made, it will never rust. Care has to be taken in handling both the solid alloy and the plastic metal, as they are poisonous.

The cost of bonding a track will vary largely with the type of bond used, and also, in the case of copper bonds,

with the number of bonds per joint. Bonding with 3 No. 000 "Chicago" or "Crown" bonds per joint, will cost about £200 per mile of single track, while a single "Plastic" bond per joint would not cost more than £100 per mile. These figures will again be modified, depending upon whether the bonding is done when the track is being laid, or whether the road has to be opened at each joint.

Cleaning the Track.—The necessity for keeping the rails in a clean condition was mentioned in Chap. I., from the point of view of lowering the tractive resistance. It is of even more importance for electrical reasons. When the return circuit is formed by the rolling contact of the wheels on the rails, any non-conducting substance on the rails, in the shape of dirt, etc., interposes a considerable resistance to the passage of the current. This not only causes great waste of energy, but also serious sparking and flashing, as the car passes.

To clean the track, track-scrapers, either attached to the cars, or worked by hand, are generally used, in conjunction with a special watering-cart. The cart has flanged wheels, which fit the rails, and is either taken over the track by a horse, trailed behind an electric car, or driven by its own motor equipment. A small pipe from the tank is led down close to the face of each rail, so that the water is projected into the groove. This softens the dirt, and the scrapers should follow immediately, lifting the dirt from the groove, and cleaning the face of the rail.

Too much attention cannot be paid to ensuring a clean track. The results will more than repay all the cost of the labour.

Resistance of Bonded Joints.—Bonds are usually placed on the sides of the rails facing inwards, in order to clear

the nuts securing the fish-plates, and the track should be cross-bonded from one rail to the other, at distances of about 30 yards. The size and number of the bonds, required at each joint, will depend upon the weight of the rails and the current carried. A steel rail, weighing 100 lbs. per yard, and having therefore a cross sectional area of about 10 sq. in., would be equal in conductivity to a copper cable of about 0·9 sq. in., the relative conductivities of copper and steel averaging 11 to 1. To make the conductivity of the bond equal to that of the rail in this case, would mean about six No. 0000 copper bonds. It has not been the practice, however, to bond as heavily as this, three No. 000 bonds or two No. 0000 bonds being more usual.

It is very difficult indeed to give any reliable figures for the values of the resistances of joints when bonded, as everything depends upon the kind of contact between the bond and the rail. Actual experiments upon a double track in Plymouth, 1·5 miles long, laid with 92 lb. rails, in 30 ft. lengths, and with joints bonded with three No. 000 Chicago bonds, gave a resistance of 0·015 ohm per mile for the four rails, or an average of 0·06 ohm per mile for a single rail, including the bonds.

Cast welded joints, when properly made, should not require bonding. But it is better to use at least a single copper bond, in the event of the accidental breakage, or failure, of any joint.

CHAPTER IX

OVERHEAD SYSTEMS

General—Methods of Suspension—Span-wire Suspension—Under- and Side-running Trolleys—Side-post Suspension—Centre-post Suspension—The Trolley Arm—The Trolley Mast—The Fixed Trolley Head—The Swivelling Trolley Head—Insulation of Trolley—Trolley in Use—Trolley Wheel—Posts—Erecting Posts—Bracket Arms—Rosettes—Ears—Bracket-arm Insulators—Straight-line and Pull-off Insulators—Turnbuckle Insulators—Globe Insulators—Section Insulators—Frogs—Crossings—Trolley Wires—Erecting the Wires—Curves—Guard Wires—Double-trolley System—Costs.

General.—Under the title of overhead systems may be considered all those methods of conveying current to moving vehicles, which use a conductor or conductors suspended over the roadway. Speaking broadly, there is only one overhead system, but as there are considerable differences in the details of its application in various places, we are perhaps justified in using the plural term.

By far the greater portion of the electric tramways of the world are being worked by overhead wires at the present time. In the United Kingdom, out of one hundred lines, either working or being constructed, only three are using other systems.

In Wolverhampton there is a line in operation worked by the surface-contact system, while the underground-conduit system is being constructed by the London County Council, and (for a short length only) by the Bournemouth

Corporation. The opposition, on the parts of certain Local Authorities, and others, to the use of overhead conductors, has been most pronounced, but, in spite of all obstacles, the system has proved its claim to be the cheapest, and simplest, method yet introduced for working street tramways.

Connection having to be maintained between the over-head wire and the moving car, the former must be bare, and, as a consequence, must be suspended at such a height above the roadway, as to obviate any danger of its being touched, either by persons or by vehicles. The Board of Trade has fixed the minimum height at 17 ft.* The usual method of making the continuous connection with the wire, is by means of a small grooved wheel, called the "trolley wheel," carried at the end

Fig. 111.

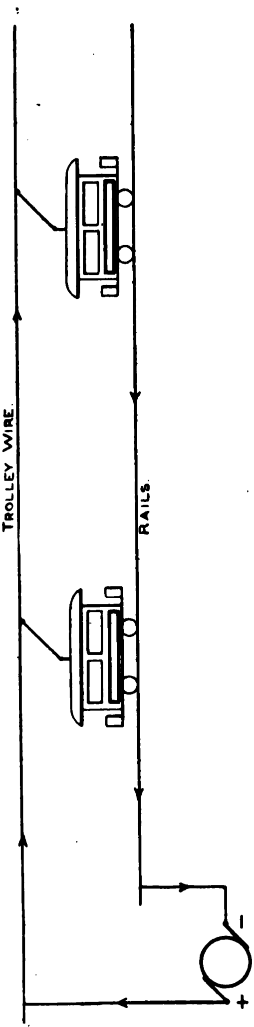


DIAGRAM OF TRAMWAY CIRCUIT.

* See "Board of Trade" regulations in Appendix. Also page 285.

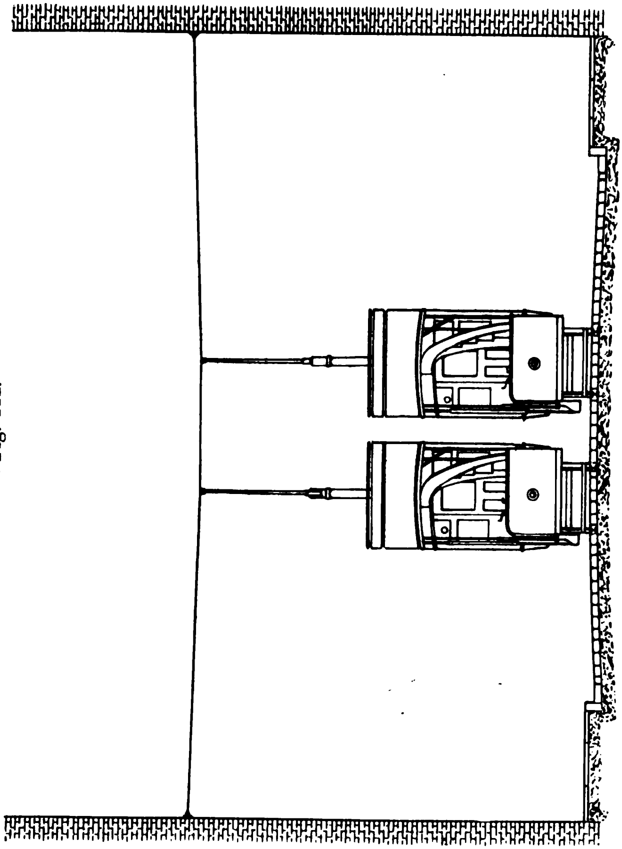
of the "trolley arm," which projects from the roof of the car. The trolley wheel runs on the underside of the overhead wire, and is pressed into contact with it, by means of strong springs at the base of the trolley arm. An insulated cable passes down the inside of the arm, and connects the trolley wheel with the controlling apparatus, and with the motors of the car. The return circuit is usually formed by the rails, as explained in Chap. VIII. Fig. 111 shows, in a diagrammatic manner, the path of the current from and to the generating station.

It is impossible to erect overhead conductors, suitable for tramway work, without making them apparent to the passer-by. As a consequence, great objection to their use has been, and often is, made, by the residents of the districts through which the tramways are to run. The early examples of overhead construction were anything but sightly, and there are several instances, of even modern work, where little attempt would appear to have been made to render its appearance unobjectionable. This is a matter for regret, since it is perfectly easy, and practicable, to design and erect a line, which shall not look unsightly, in almost any locality. It is all very well to say, that the advantages of electric traction will far outweigh any sentimental objections to the overhead construction. So they may, but that is no reason why the work should not be carried out in the very neatest, and most artistic, manner possible.

The overhead wires are the same, whatever the means employed for supporting them, but, as the appearance of the line depends entirely upon the style of the erection, it would be well first to consider generally the various methods, before going into the details of the apparatus used.

Methods of Suspension.—There are two principal methods of carrying the overhead conductors, viz.—(1) by Span Wires, and (2) by Bracket Arms.

Fig. 112.



SPAN-WIRE CONSTRUCTION (*a*).

The former may be sub-divided into—

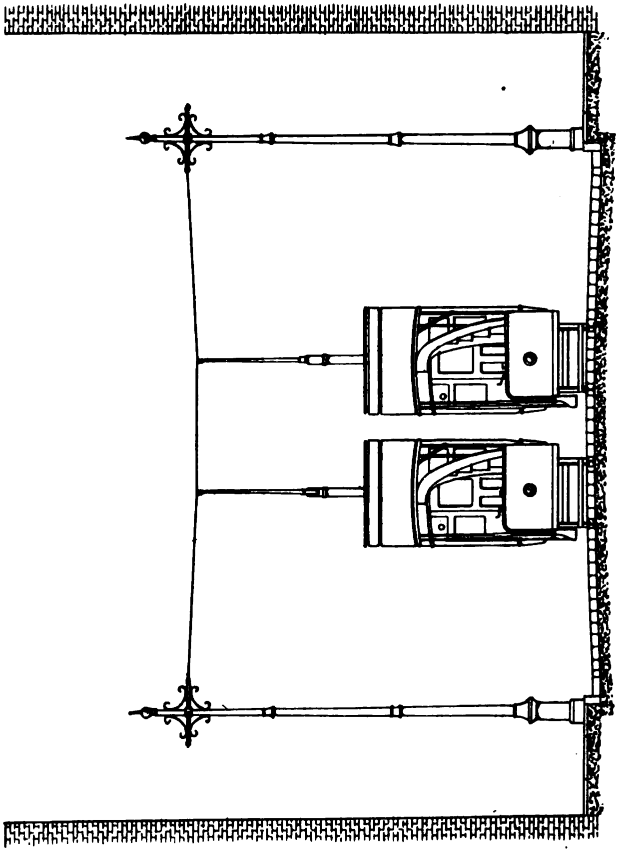
(*a*) Span wires from building to building.

(*b*) Span wires from post to post.

(*c*) Span wires from building to post.

The latter may be sub-divided into—

Fig. 113.



SPAN-WIRE CONSTRUCTION (*b*).

(*a*) Posts on one side of the road, with bracket arms carrying both conductors.

(*b*) Posts on each side of the road, with bracket arms carrying only one conductor.

(*c*) Posts between the tracks, or centre posts, with double bracket arms each carrying one conductor.

The following figures represent the cross-section of a

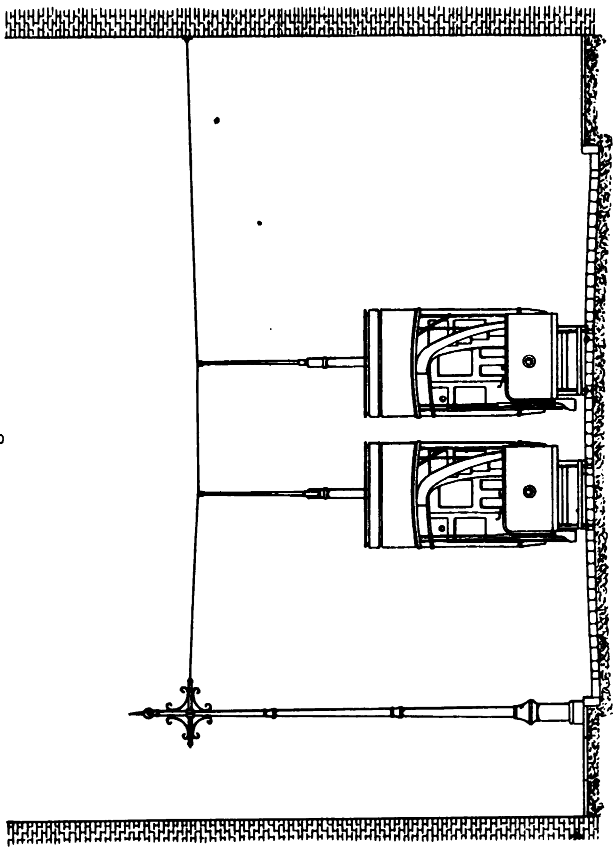


Fig. 114.

SPAN-WIRE CONSTRUCTION (*c*).

street, laid with a double tramway track, and with the overhead construction carried out in the various methods above named.

Span-wire Suspension.—Fig. 112 shows the conductors supported over the centres of the tracks, by means of span wires from building to building. The spans consist of

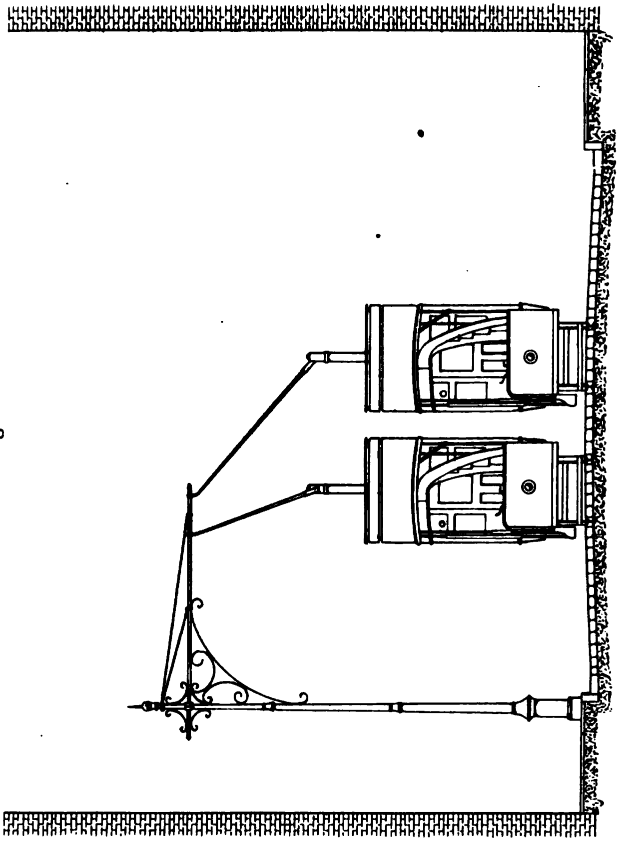
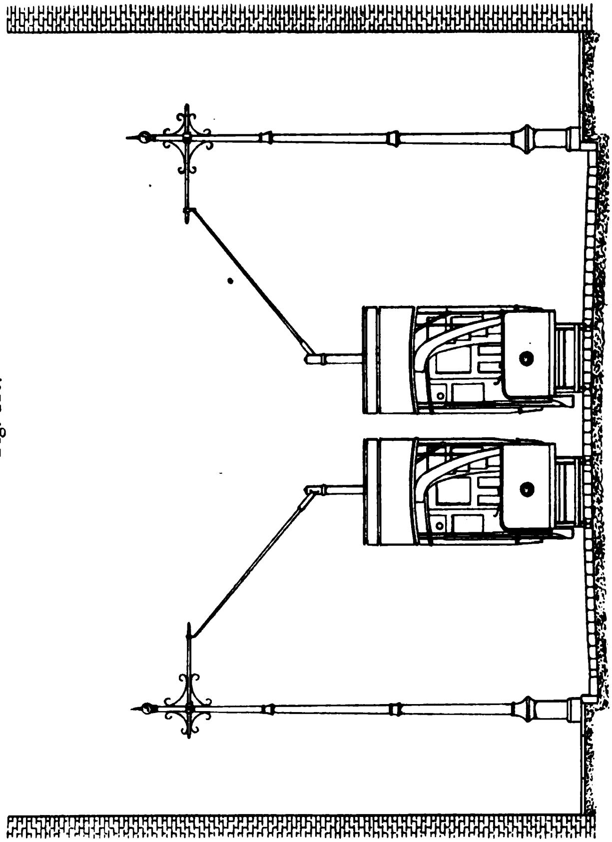


Fig. 115. BRACKET-ARM CONSTRUCTION (*a*).

stranded steel wires, and they are attached to rosettes securely fixed to the face of the buildings. Where buildings suitable for standing the strain can be found, this is a very neat and cheap form of construction.

It frequently happens that the tramway runs through a district, where there are either no buildings at all, or else buildings to which it would be difficult or unsafe to attach.

Fig. 116.



BRACKET-ARM CONSTRUCTION (*b*).

In such a case span wires may still be used, stretched from one side of the road to the other, between a row of steel posts, fixed close to the kerbstones, as shown in Fig. 113.

This construction is not so neat as the former, but it is often the only way in which span wires can be used.

In Fig. 114 is shown a compromise between the two foregoing methods, a post being used on one side of the road, and a rosette on the other. This is sometimes necessary, either because the building on one side is unfit to attach a span wire to, or because the consent of the owner of the building cannot be obtained,* or because a post is required to carry an arc lamp, and is made to answer the double purpose.

Span-wire suspension has the great advantage of flexibility in construction. The overhead conductors may be supported at any point, from one side of the road to the other, either directly over the tracks, or as near to the kerbs as may be desired. When brackets are used, the lengths of the arms have to be carefully considered, in order that the overhead wire may be in its correct position.

Under- and Side-running Trolleys.—As to what is the correct position for the overhead wire is by no means universally agreed. A number of engineers prefer to fix the wires directly over the centre lines of the tracks, and to use what is called an "under-running trolley," or one which always runs fore and aft with the car, directly under the wire. Others claim that the right thing is to fix the wires to the side of the tracks, and to use a "side-running trolley," or one which reaches out, over the side of the car, to meet the wire.

Before we consider the merits and demerits of the two systems in actual working, let us notice their effect on the overhead construction. So far as span-wire suspension on straight roads is concerned, it does not matter whether

* Some towns have obtained Parliamentary powers, whereby they can attach to buildings without asking the consent of the owner.

the under-running or the side trolley be used, since the conductors can be supported anywhere over the road. On curves, however, as will be seen later, the use of the side trolley allows a less complicated arrangement, and this applies equally to either span-wire or bracket-arm construction.

With a double track, and an under-running trolley, span-wire suspension is the only practicable method, except centre posts, since, with side posts, the bracket arms would have to be abnormally long, to carry each wire over the centre of its track.

The judicious use, however, of the side-running trolley with a swivelling head, enables overhead construction to be carried out, either with span wires or bracket arms, in the most effective and sightly manner. Considering that the large majority of British electric tramways use a trolley of this type, it is a matter both for surprise and regret, that so little advantage has been taken of its possibilities, in designing the overhead work.

The under-running trolley, with a fixed head, is not much used in this country at the present time, even in those cases where the wires are kept over the centres of the tracks, but in America its use is universal, while, on the continent of Europe, a "bow" collector is common.

Side-post Suspension.—Fig. 115 shows a post on one side of the road, with a bracket arm carrying both conductors. This is a very usual form of construction, and, although the side-running trolley enables a much shorter bracket arm to be used, than would be possible with an under-running trolley, yet in many instances the arms have been kept far longer than is really required.

In Fig. 116 we have a row of posts on each side of the road, as in Fig. 113, but, instead of span wires, short bracket

arms are used. The overhead wires are kept well over to the side of the track, the trolley arm, on each car, reaching over to its own wire. So far as the Author is aware, this method was first indicated in the specification of Dickinson's swivelling trolley patent (No. 5461, A.D. 1891), and, in his

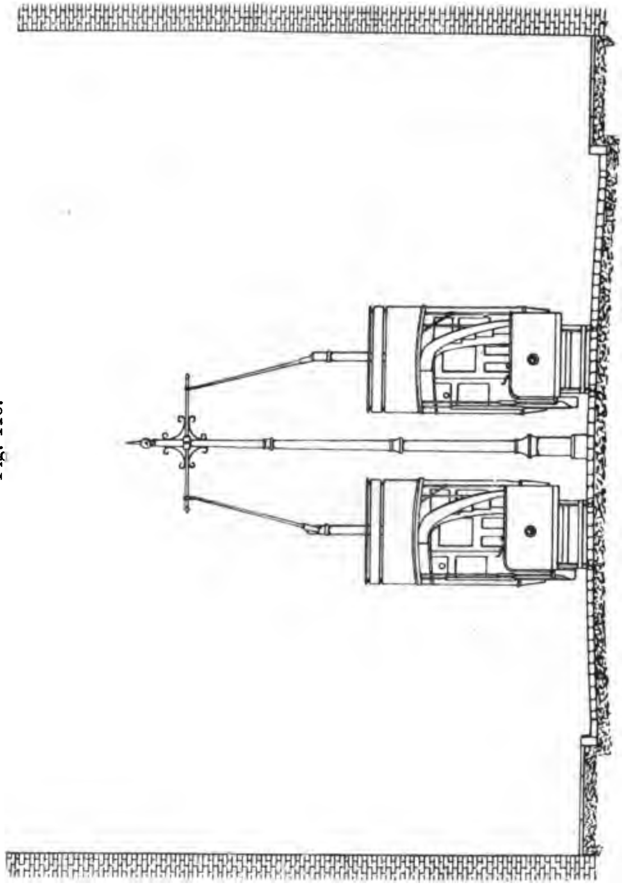
Fig. 117.

BRACKET-ARM CONSTRUCTION IN PLYMOUTH.

opinion, it is, perhaps, the best which could be employed. It leaves the centre of the roadway quite clear of all overhead work, and, standing on either footpath, the wire on the opposite side of the road is hardly visible, against the background of the buildings. Fig. 117 gives a view of a roadway in Plymouth, with the overhead work carried out in this manner. If the tramway posts be used for light-

ing, the advantage of having them on each side of the street will be obvious. This method is also particularly adapted for use with the "3-wire" system (see page 110).

Fig. 118.



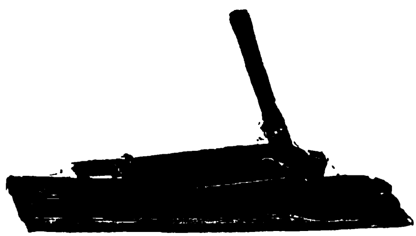
CENTRE-POST CONSTRUCTION.

Centre-post Suspension.—In Fig. 118 are shown centre posts, placed between the tracks, which require to be some 6 ft. apart, in order to find space for the small island, or

"refuge," at the foot of each post. Even with an underrunning trolley, the bracket arms need not be exceedingly long, and this is a favourite method of construction, where the necessary space between the tracks can be obtained. Centre posts are useful in dividing the ordinary traffic into two streams, although, where traffic regulations are not strictly enforced, they are not much liked by drivers.

On some of the earlier lines, having a single track, only one overhead conductor was used, with turnouts corresponding to those on the track. Experience has shown that two complete conductors are far preferable, not only

Fig. 119.



TROLLEY BASE FOR SINGLE-DECK CAR.

because by their use points, or "frogs," in the overhead wires are avoided, but also because the current-carrying capacity is doubled, while the wear and tear of the wire is halved.

The Trolley Arm.—The trolley arm consists of a tapered steel tube, without weld or joint, and is generally from 12 ft. to 15 ft. long. It is held, at its lower end, in a swivelling carriage, at the top of the car, so that it can turn horizontally in any direction. On single-deck cars (*i.e.* cars without seats on the roof) the swivelling carriage is fixed directly on the roof, while, on double-deck cars, a

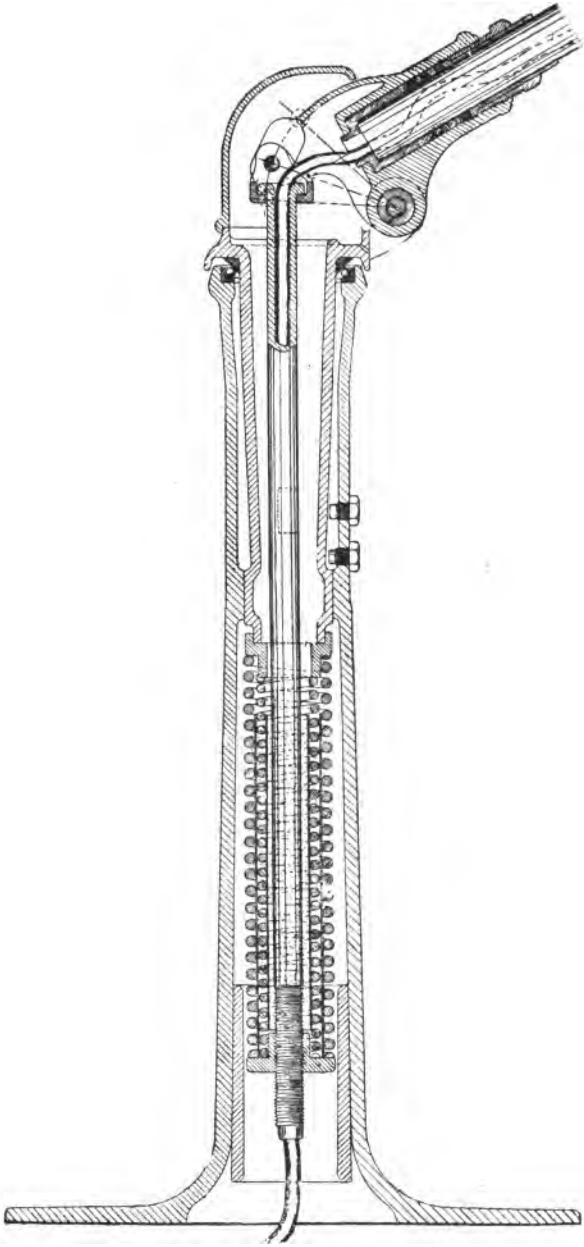


Fig. 120. SECTIONAL VIEW OF TROLLEY MAST FOR DOUBLE-DECK CAR.

vertical mast has to be used, in order to lift the trolley arm above the heads of passengers.

Fig. 119 shows a type of trolley base for a single-deck car, and Fig. 120 a sectional view of a trolley mast for a double-deck car.

The Trolley Mast.—The trolley mast requires to be of great strength, not only because of the overhang of the

Fig. 121.

BROKEN TROLLEY MAST.

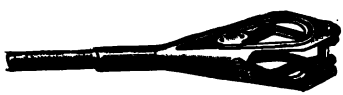
trolley arm, but also because of the severe strains thrown upon it, should the trolley arm catch in the overhead line. This is liable to occur, even in the best-designed systems, and several accidents have taken place from this cause. The weakest part of the mast is where the vertical stem joins the base, and many methods of construction have been tried. In order to do away with the joint, cast steel has been used throughout, but this is an uncertain

material, and, to obtain sufficient strength, it means a very heavy mast.

A welded steel tube has also been tried, flanged out at the lower end, and welded into a steel base-plate. If a perfect weld were obtained, this would result in a strong and light mast. But, the metal being so thin, there is great danger of its becoming burnt during the process. Fig. 121 shows the lower end of a trolley mast of this type, which broke in its place on the top of a car, and clearly indicates the weakness of this type of construction.

Another method is to use a steel tube for the vertical part of the mast, and to step it into a cast-iron socket, with a base-plate. This makes a heavier-looking mast than the former, but, if properly made, it is, perhaps, one of the best forms.

Fig. 122.



FIXED TROLLEY HEAD.

Trolley masts are usually fixed in the centre of the car roof, which requires to be considerably strengthened in consequence. An oblong base, as shown in Fig. 121, is generally used, and, for an under-running trolley, is quite satisfactory. But, for a side-running trolley, a special base should be used, having an equal bearing in each direction. This can easily be obtained, by making the base either "star" shaped, or circular, in plan.

The Fixed Trolley Head.—The ordinary type of fixed trolley head is shown in Fig. 122. As will be seen, it consists of a socket, into which the end of the trolley arm

is secured, and a harp for carrying the spindle of the wheel. The wheel itself is usually made of gun-metal.

A trolley head of this type will not allow the overhead wire to be more than about 2 ft. out of the centre line, and, even then, only for a very short distance, since the wheel groove must be practically parallel with the wire to obtain satisfactory running.

The Swivelling Trolley Head.—The swivelling trolley

Fig. 123.

SWIVELLING TROLLEY HEAD AND WHEEL.

head, as its name implies, is one in which the trolley wheel is held in a carriage, pivotted vertically at the end of the trolley arm. A well-known pattern is shown in Fig. 123. In order to insure perfect freedom, the swivelling carriage is sometimes supported on ball bearings. Such a trolley head, when combined with the swivelling carriage at the base of the trolley arm, will follow the overhead wire with perfect freedom, although its distance, from the centre line

of the track, may vary from 8 ft. to 10 ft. on one side of the car, to a similar distance on the other. A stop, to prevent more than about one-third of a revolution of the carriage, would be an improvement to the ordinary swivelling trolley head.

In designing the overhead system, for use with the swivelling, or side-running, trolley, it is well to keep the distance of the wire, from the centre line of the track, as constant as possible, in order to avoid any swaying about of the trolley arm, although, of course, such a construction is not always possible.

Experience has shown that, with a trolley arm 15 ft. long, a road can be successfully operated, at speeds up to fifteen miles per hour, with a side reach of the trolley of from 8 ft. to 10 ft.

Insulation of Trolley.—When top-seated cars are used, the trolley head is insulated from the trolley arm, and the arm from the mast, in order to insure perfect safety to passengers, and, in addition, the trolley arm is wrapped with insulating tape. The mast should always be earthed by direct connection to the wheels, and an automatic switch, arranged to ring the electric signal bells on the car, should the mast become "alive," would be very useful.

Trolley in Use.—The trolley arm must always be set so that it trails after the car, and, when the car is run in the reverse direction, the trolley arm must be changed round. To do this, a light cord is kept attached to the trolley head, so that the conductor can pull the trolley arm down for a few inches, in order to clear the wheel from the wire, and then turn the arm round on its swivelling carriage, and place the wheel on the wire again. Wherever the under-running trolley is used, and, in many cases, even where the swivelling trolley is used, it is customary to allow the

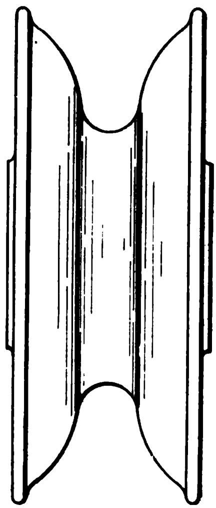
trolley cord to dangle, at all times, from the end of the trolley arm. In some examples of overhead work this is quite necessary, since there is a tendency for the trolley wheel to leave the wire at curves, frogs, etc. The car conductor may often be seen holding the trolley cord at such points, both in order to place the wheel quickly on the wire again, should it come off, and also to guide the wheel over the awkward places. Such a condition of things, however, should never be, and it is indicative of bad design. With well-arranged overhead work, and a good swivelling trolley head, it ought to be, and is, quite possible to operate a road with the trolley cord tied up the whole time (except when it is required to change the arm round), and without any risk of the trolley wheel leaving the wire.

In order to prevent any liability of the conducting cable, which passes down the interior of the trolley arm and mast, becoming broken off, on account of the continual changing round of the trolley arm, a stop is always provided, which prevents the swivelling carriage, carrying the trolley arm, from turning round more than a complete revolution in either direction. The arm has therefore to be moved round always on the same side of the car. A second stop, on the opposite side of the mast to the first one, to prevent more than a half sweep of the trolley arm, would often obviate an accident. It should be arranged to be in action, whenever the trolley arm is in its normal position, or when the wheel leaves the wire. The act of pulling down the arm, by means of the trolley cord, could disengage the stop, and, by keeping it pulled down, it could be swung right round.

Trolley Wheel.—The shape of the groove in the trolley wheel has an important bearing on the satisfactory running

of the trolley. The under-running trolley, with a fixed head, requires a wheel with a simple U-shaped groove. But a side-running trolley, with a swivelling head, runs much better with a wheel grooved more after the shape shown in Fig. 124. The exact shape of the groove should really be determined by experience in each case, and more attention to this matter would often result in smoother running, as the wheels, supplied by the various Contractors, are not always grooved to the best shape, for the particular line on which they are used.

Fig. 124.



SHAPE OF GROOVE IN TROLLEY WHEEL.

Posts.—The posts, used for supporting either span wires or bracket arms, have to bear very heavy strains. They are usually made of lap-welded steel, either tapered, or else in three sections fitting into each other. In the Appendix is given a sample specification for steel posts of this class.

The diameters and weights of the posts vary according to the work they have to do. Those which carry the wires on curves, or at the ends of a line, have to be much stronger than those on a straight road. The Board of Trade requires that the overhead conductors shall be supported at distances not exceeding 120 ft. On curves this distance must, of necessity, be considerably lessened.

Erecting Posts.—The posts are usually set in concrete, to a depth of about from 5 ft. to 6 ft., depending upon the

nature of the soil. In excavating the holes, great care should be taken not to disturb more ground than is absolutely necessary, and any filling should be of concrete, and not of soil. Unless the ground is very hard, it is advisable to place a large flat stone at the bottom of the hole, to take the weight of the post, and, before the concrete is put in, the post should be carefully set at the proper rake. In order that the posts shall be truly vertical when the overhead wire is erected, and tightened up, it will be found that every one must be set, more or less, out of the perpendicular at first. The exact amount will, of course, depend upon the particular strain each post may have to bear, but it varies from two inches at the top of the post, on the straight, to a foot or more for the terminal posts.

To improve the appearance of the posts, and to make them as sightly as possible, it is usual to fix an ornamental finial at the top, and neat cast-iron rings to cover the joints of the various sections. The base, being a mere shell, is only for ornamental purposes, and it does not take any part in supporting the post.

When posts are used to carry span wires, the latter may be attached directly to a clamp on the post, but it is much neater to employ a very short arm, with ornamental scroll-work, as shown in Fig. 113. Scroll-work, on a larger scale, is also used on the longer bracket arms employed in that type of construction. In many cases it is of too heavy, and ornate, a character. Scroll-work, to be effective, should be light, and of very neat design. A good example is shown in Fig. 115, but, of course, there are many other excellent designs.

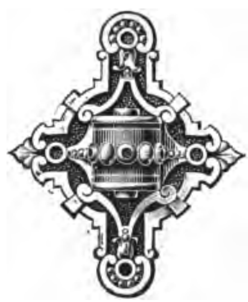
Bracket Arms.—Bracket arms are generally made of hydraulic steel tube, 2 in. in diameter. The arm is securely fixed into one half of a strong cast-iron clamp,

the other half having a small tail-piece, the two being bolted together at the top of the post. The tail-piece, which is usually about 18 in. long, is merely an ornament, and the outer end of it, and of the bracket arm, should be stopped by neat finials.

When the bracket arms do not exceed 4 ft. or 5 ft. in length, they are stiff enough to take the weight of the wire, without any additional support. When, however, as is often the case, they exceed this length, wrought-iron stays, as shown in Fig. 115, are necessary.

Rosettes.—As was mentioned earlier in this chapter, rosettes are often used to carry span and other wires. A good type of rosette is shown in Fig. 125. It has a broad base, which is bolted to the wall of the building, and the centre drum, to which the wires are attached, is carried on a strong steel axle, with a rubber cushion to prevent any vibration affecting the building. Rosettes are very useful, as they take the place of heavy posts, but, in order that they may be a success, they should be attached only to buildings which are in a good state of repair, and then only in the most careful manner.

Fig. 125.



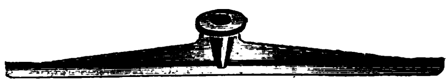
WALL ROSETTE.

If possible, the bolts should be taken right through the wall, with a back-plate, but, where this cannot be done, and the wall is a sound one, long bolts, cemented or leaded in, will give good results. Too much care cannot be taken in fixing rosettes, since they are often called upon to bear a strain of 1,000 lbs. and over.

Ears.—The overhead wire is carried by long gun-metal ears, which are grooved to fit the wire, and have, on the top side, a screwed boss, with a stiffening web, for attachment to the insulators. Such an ear is shown in Fig. 126. The thin edges of the groove are hammered over the wire, so as to clip it over the whole length, and it is often advisable, in addition, to solder the ear and the wire together.

Since the trolley wheel has to pass the ear, it is very essential, for smooth running, that the ear should not add appreciably to the diameter of the wire, and herein comes the difficulty of making an ear, which shall be strong enough, mechanically, to support the wire, and yet have no appreciable thickness. A common length for trolley-wire

Fig. 126.



TROLLEY WIRE EAR.

ears is 15 in., but experience has proved that these short ears are not nearly so good as long ones, and 24 in. should be the minimum length for good work. Ears which are used at curves should be even longer, and 36 in. is not too long in such cases.

Bracket-arm Insulators.—The insulators, which carry the ears, are of many varieties, depending upon their methods of support. Those which are fixed to bracket arms, are called "bracket-arm insulators," and one is shown in Fig. 127. A steel bolt (gun-metal would be better), embedded in a special insulating material, is screwed into the boss of the ear, and is carried in, and protected by, a bronze hood, or skirt. The hood itself is carried from a cross bolt, on the lower side of a split clamp, which is

bolted to the bracket arm. Porcelain, or such-like insulating material, is seldom used for trolley-wire construction, since what is wanted is something which shall be, not only a good insulator, but also mechanically strong. There are various makes of insulating materials on the market, the composition of which is very similar, all, however, being more or less a trade secret. The bronze hood is necessary, in order to protect the insulating material, both from the weather, and also from accidental blows from the trolley, should the latter leave the wire. The insulators are always made in such a way, that the ears can be soldered to the wire, and attached to the insulators afterwards, the steel bolt being removable.

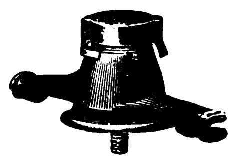
Fig. 127.

BRACKET-ARM INSULATOR.

In all cases of overhead construction, it is advisable to use what is known as double insulation, and, in the case of bracket-arm insulators, this is usually provided by means of an insulating sleeve on the bracket arm, over which the insulator clamp is bolted.

Straight-line and Pull-off Insulators.—The other types of insulators differ from the one just described only in their methods of support. For use with span wires, the insulator is made with special wings, or lugs, so that it can be attached to the span wire after the latter has been erected. This type of insulator is shown in Fig. 128, and is called a "straight-line

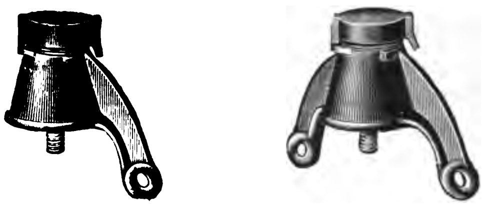
Fig. 128.



STRAIGHT-LINE INSULATOR.

insulator." Insulators for use on curves, when pull-off wires are used, are called "pull-off insulators," being distinguished as single and double pull-off, according to whether they have single or double lugs. The former is used for the wire farthest from the post, and the latter for the wire nearest the post, as shown in Fig. 129. The

Fig. 129.



SINGLE AND DOUBLE PULL-OFF INSULATORS.

lugs must be dropped, so that the pull-off wire comes in line with the trolley wire, or otherwise the insulators will be pulled out of the vertical. The ordinary type of "pull-off" insulator has the lugs too close together for the proper use of the swivelling trolley head, and a wider spread could be given with advantage.

Turn-buckle Insulators.—Double insulation is obtained, when span or pull-off wires are used, by insulating these wires themselves from their supports. As it is necessary to be able to adjust, or tighten up, span or pull-off wires, it is usual to employ what is known as a "turn-buckle

Fig. 130.

TURN-BUCKLE INSULATOR.

Fig. 131.

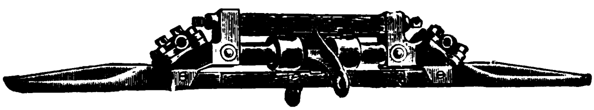
GLOBE INSULATOR.

insulator," a type of which is illustrated in Fig. 130. This turn-buckle will take up 6 in. of slack wire.

Globe Insulators.—Span wires are usually provided with a turn-buckle insulator at one support, and with what is known as a "globe insulator" at the other. A globe insulator consists of a pair of interlocked rings, which are kept from actual contact with each other, by means of an insulating ball into which they are embedded. This insulator is illustrated in Fig. 131. Although the metallic parts are insulated from each other, yet, should the insulating material be destroyed, the line would not fall. Both the globe and the turn-buckle insulators will stand very heavy strains, tests having been made up to 3,000 lbs. without affecting the insulating material.

A favourite method, in bracket-arm construction, is to

Fig. 132.



SECTION INSULATOR.

use a short span wire stretched between a couple of globe insulators attached to lugs on the arm. This gives a more flexible support than when the insulator is clamped direct on to the arm.

Section Insulators.—In this country, the Board of Trade regulations require that the overhead conductors shall be divided into lengths not exceeding half-a-mile. In order to effect this, special "section insulators" are used. These must not only be provided with efficient clamping terminals for the trolley wire, and for the connecting cables, but also with an insulated strip, which will carry the trolley wheel across the gap between the two conductors, without any shock. The strip should be removable for renewal, without taking the strain off the wires. These

section insulators are, perhaps, the most unsatisfactory of the overhead line material at present on the market. It is exceedingly difficult to design and make an insulator of this type. One of the best is shown in Fig. 132. It can be obtained either for attachment to a bracket arm, or to a span or pull-off wire.

Frogs.—It was mentioned, earlier in this chapter, that, by the use of two overhead conductors, one for the up cars, and the other for the down cars, points, or frogs, in the overhead wires were avoided. This is true only when there are no track junctions, or branches, to provide for.

Fig. 133.

FROG FOR SIDE-RUNNING TROLLEY.

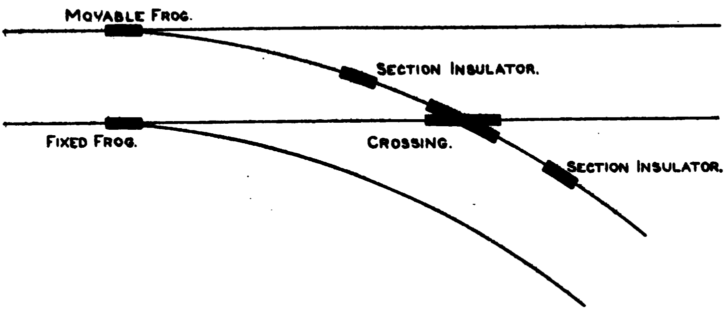
In such cases, it is, of course, necessary to branch the overhead conductors, in order to allow the cars to run on the other routes.

Frogs are of two principal types, those used where the overhead wires diverge usually having a movable tongue, and those used where two wires converge having a fixed tongue, in a similar manner to the movable and open points on the track. When the tongue is movable, it is preferably controlled by a lever fixed to the adjacent post, so that the pointsman, or conductor, may divert the trolley to the correct wire. When the under-running trolley is used, the wheel is guided in the frog by means of a centre tongue, and a centre pin, on which the wheel runs as on

the overhead wire, but this type of frog is not always satisfactory, when used with the side-running trolley. It is often necessary, in this case, to guide the trolley wheel by its flanges, as well as by the groove. Fig. 133 shows a frog of this class.

Crossings.—Crossings are always necessary, when frogs are used on a double track, since the one wire must cross the other. In consequence of the necessity of being able to cut out any overhead wire, in case of accident, it is usual

Fig. 134.



USE OF UNINSULATED CROSSING AT JUNCTION.

to make such a crossing an insulated one, in order that the two overhead conductors may be kept electrically distinct. It is, however, exceedingly difficult to make an insulated crossing, with a less angle than 75°, and, for crossings at junctions, this is often much too great. The whole difficulty, however, can be got over very easily, by using an uninsulated crossing, with a section insulator within a few feet of it, on either side, as indicated in Fig. 134. There is, of course, no difficulty in using insulated crossings, when the angle of intersection is anything between 75° and 90°. Fig. 135 shows an insulated crossing, and Fig. 136 an

uninsulated crossing. Both frogs and crossings should be made of the best gun-metal.

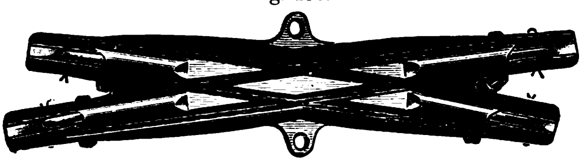
Frogs can be obtained for either span-wire or bracket-arm suspension, while crossings are usually supported on

Fig. 135.

INSULATED CROSSING.

the overhead wires themselves. It is often necessary, however, to use stay wires in connection with them. In order to ensure satisfactory running of the trolley, through points and crossings, it is of great importance that the

Fig. 136.



UNINSULATED CROSSING.

angles of intersection should be made exactly to suit the line, or curve, of the overhead wire. In too many instances stock frogs and crossings have been used, with the angles not even approximately correct, with the only possible result of rough running, and frequent displacement of the trolley wheel.

Trolley Wires.—The trolley wires should be made of high conductivity, hard drawn, copper. The most usual

diameter of the wire has been 0·325 in., but a number of recent lines have employed wire 0·409 in. diameter. This larger wire requires a heavier type of fitting, but it is much to be recommended. Not only is it a better conductor, but it is much stronger, and not nearly so liable to sway about as the lighter wire. Great care should be taken to procure only the very best wire. The breaking strain should be at the rate of not less than 22 tons per sq. in. of cross section, and the variations in diameter should in no case exceed 0·0005 in. The wire should be perfectly free from flaws, or cracks, and should have a smooth, hard-polished surface. No joints should be allowed in the finished wire, all necessary joints being silver brazed in the rod, before final drawing.

Section insulators being used at distances not exceeding half-a-mile, the wire should be delivered upon drums in lengths sufficient to reach, without joints, from one section insulator to the other.

Erecting the Wires.—When the posts have been erected in position, and the bracket arms and span wires fixed, with the insulators (but not the ears) in place, the trolley wire is strung up in a rough manner. The drum, containing the wire, is mounted upon a special truck, so that it may turn freely. The end of the wire is securely anchored at the end of the line, and as much of the wire run out as can be conveniently done. By means of a tower wagon, such as is illustrated in Fig. 137, the trolley wire is raised up to the bracket arm, or span wire, and temporarily fastened by means of stiff iron hooks, or galvanized wire. A special clamp, called a "come-along" clamp, is fixed on the wire, and, by means of tackle, the wire is pulled up and temporarily anchored at intervals. Care has to be taken in going round curves, to allow the correct amount of slack.

The drum, carrying the wire, should be provided with an efficient hand-brake, in order that the rate of unwinding may be controlled. It is very important that the wire

Fig. 137.

TOWER WAGON.

should be anchored at curves, and other places where the direction of the strain alters, during the preliminary erection. When the whole line has been put up in this

manner, it should be gone over several times, and tightened up, prior to the final finishing off.

Curves are the most difficult parts of the line to erect satisfactorily, and it is usual to commence the permanent work by fixing the ears and insulators first at these places. Temporary anchor wires are used to take the strain on one side of the curve, and then, by means of a "come-along" clamp, fixed on the wire at the end of the section, if the line be straight, or close to the next curve, the intermediate length of wire is tightened up to the correct amount. The sag should be about 10 in. in a 120 ft. span, for an average temperature, and should not exceed 15 in., even in the warmest weather.

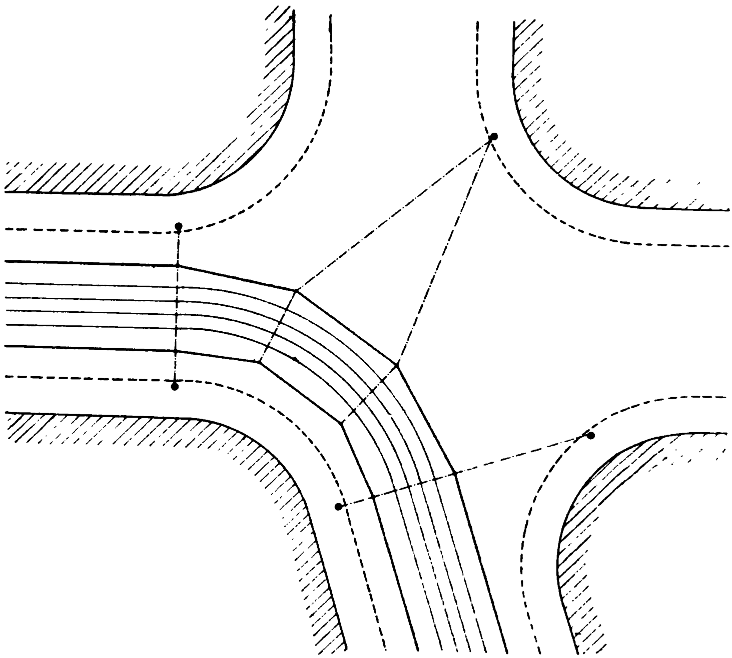
The ears are next put into place on the wire, securely soldered, and carefully smoothed off with a file. This can be done before they are attached to the insulators, and, when the soldering is finished, the insulator bolt is screwed into the ear, thus holding the wire firmly in position. In erecting the trolley wire, it is of the utmost importance, that the anchoring should not be released until the strains are properly taken, or otherwise the span wires may be pulled down, or the bracket arms shifted out of place. It is usual to place permanent anchor wires, attached to special ears, called "anchor" ears, on each side of section insulators and heavy curves, in order to prevent the whole line slipping back, should either of the supports at these places give way. At the terminal posts the wires are permanently secured by means of a terminal clamp, a turnbuckle insulator, and a globe insulator.

Curves.—The most usual way to form curves in the overhead wire, is by means of pull-off wires. A sample curve is shown in Fig. 138, a special post being used for the pull-off wires. Sometimes, however, it is not convenient to use

a post in this position, and in such cases the curve may be formed by means of pull-off wires, and a "bridle" from two adjacent posts, as shown in Fig. 139.

These two figures show curves suitable for the side-

Fig. 138.

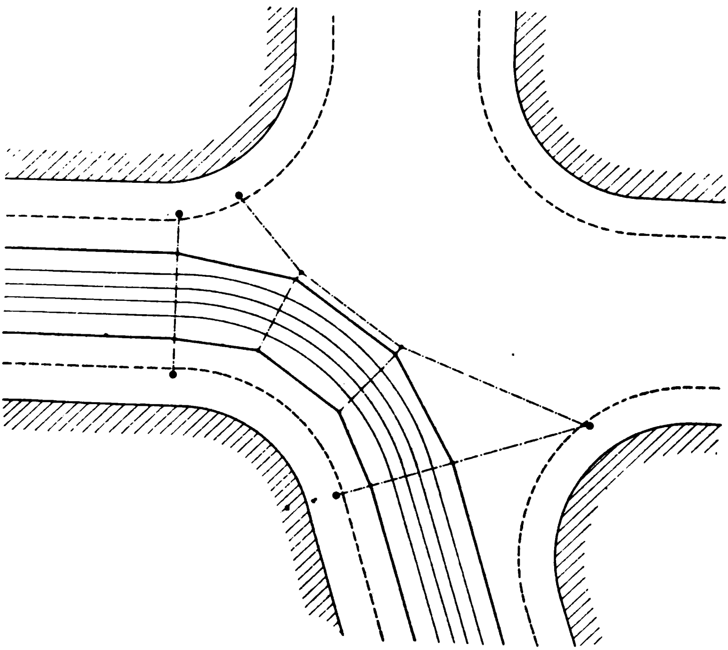


CURVE FOR SIDE-RUNNING TROLLEY, WITH PULL-OFF WIRES.

running trolley with a swivelling head, where, as we have already noticed, there is no necessity for the overhead wire to follow closely the line of the track. Curves for use with the under-running trolley, however, require much more careful treatment, as, in order to prevent the trolley from leaving the wire, they must be put up practically exactly

parallel with the curvatures of the track. Fig. 140 shows the type of construction necessary for the under-running trolley, on the same curve as that in the preceding figures, from which it will be seen how much simpler the overhead con-

Fig. 139.



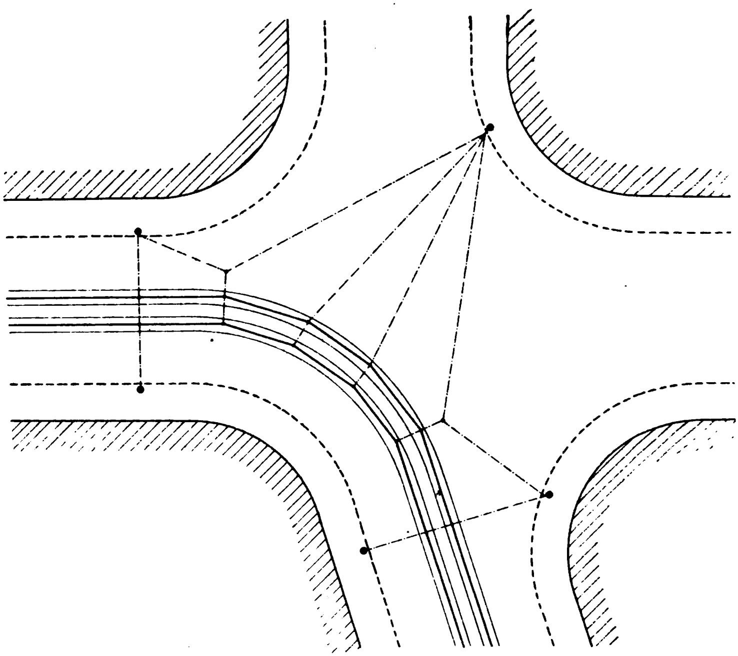
CURVE FOR SIDE-RUNNING TROLLEY, WITH BRIDLE.

struction can be made, by the use of the side-running trolley.

Guard Wires.—The overhead conductors have to be kept at a minimum height of 17 ft. above the roadway, to prevent any likelihood of personal contact with them, but 21 ft. at the ears is the usual height with double-

decked cars. A danger, which is always present, however, is that of telegraph or telephone wires falling upon the trolley wires, and dangling with live ends in the street. To minimize this risk, and, at the same time, to protect

Fig. 140.



CURVE FOR UNDER-RUNNING TROLLEY, WITH PULL-OFF WIRES.

the telegraph or telephone apparatus, which may be attached to these wires, the Board of Trade, and the Post Office authorities, require that some form of guard shall be used, which will prevent the contact between other wires and the trolley wires, should the former fall. The present

Board of Trade regulation * is the outcome of a joining of hands between the Board of Trade, the General Post Office, and the National Telephone Company.

Guard wires are no doubt a certain protection in some cases, but, in many others, they are the means of causing the very accidents which they are intended to avoid. Being of necessity only small wires, they are a constant trouble to maintain, they often break when telephone wires fall upon them, and, in the Author's experience, they have been a source of far more trouble than they are worth. When they have to be used, they should in all cases be most efficiently earthed, so that, should a wire fall upon them, and curl round both the guard wire and trolley wire, as it usually does, the effect will be to blow the fuse, or open the circuit breaker, and so to cut the current off the line.

A number of automatic devices have recently been placed upon the market, with the object of at once cutting off the current, in the case of a fallen wire. But neither guard wires, nor any of these devices, strike at the root of the matter, which is to prohibit entirely uninsulated wires of any kind crossing above the trolley wires. Telegraph and telephone wires, if they must be erected overhead, should only be allowed to cross streets at right angles, the spans should be kept exceedingly short, and the wires carried as high up as possible, in order that a broken wire should not reach the street. They should be insulated at such crossings, and, if guards be insisted upon in addition to the above, they should be provided by a netting, or similar arrangement, under the telephone wires, and not over the trolley wires.

The recent accidents, which have happened at Liverpool

* See Appendix.

and other towns, have been caused just as much by the telephone wires as by the trolley wires, but, in the mind of the public, they are called trolley-wire accidents, and nothing else. It is quite time that Local Authorities should insist upon all telegraph and telephone wires being placed underground, and then there would be no necessity whatever for guard wires, or such-like unsatisfactory half-measures.

For the present, however, guard wires are insisted upon by the authorities. The usual method of supporting them, is to use a light bracket on the top of the bracket arm, or an additional light span wire over the ordinary span wire. They are usually ugly in the extreme, and often spoil what would otherwise be a neat piece of overhead construction.

Double-trolley System.—The methods of feeding the overhead conductors are dealt with in Chap. IV., where the problems connected with the use of the rails, and the return circuit, are also considered. These latter have, in some instances (not in this country), led to the use of two overhead wires for each track, with two trolley arms, the rails not being used at all as conductors. This is not a system which can be recommended for general adoption. It is practically impossible to use other than the under-running trolley with it, and, when junctions and crossings are necessary, the overhead construction becomes very complicated, as both positive and negative conductors have to be dealt with. The Author saw an instance, in America, where the double-trolley system was erected, owing to the requirement of the Local Authority that no earth return should be used, but the engineer of the line informed him that the second trolley wire was a blind, that they only had current in one, and that the rails were still used.

Costs.—The cost of overhead construction varies largely

with the class of work, the cheapest being with span wires from building to building, and the most expensive probably with posts and bracket arms on each side of the road. It is not often found possible, excepting with simple country lines, to keep to one class of construction for any great distance, owing to local conditions, and the cost of the work varies therefore in almost every case.

With two conductors, one for each track, the cost, per mile of roadway, should lie between £1,500 and £2,200, depending entirely upon the character of the work.

CHAPTER X

CONDUIT SYSTEMS

Introduction—Cost of conduit construction—Conditions warranting use of conduit—Types of conduit construction—Yokes and slot rails—Extended yokes—Side slot conduit—Conductor tee rails—Insulators—Insulator boxes—Positions of conductor tees—Special work—Changing polarity of conductor tees—Conductor tees at special work—Sectional switch pillars—Example of sectional switches—Motors and Car wiring for conduit lines—Ploughs—Plough carriers—Plough hatches—Combined conduit and trolley systems—Plough lifting devices—Earthing on combined systems—Constructing a conduit line—Draining the conduit—Cleaning the conduit—Cost of operating.

Introduction.—Notwithstanding the success which has attended the use of the overhead system, a number of persons have strong objections to its use. This has been so, even from the introduction of electric traction, and other systems have, therefore, been taken in hand, by various engineers, in order, if possible, to produce as effective and reliable a system as the overhead, without the use of visible wires. There are two other distinctive systems in practical use, not reckoning the self-contained accumulator car. These are the conduit and the surface contact systems. We will consider conduit systems in this Chapter.

It may appear an easy matter to place the bare conductors underground, in a tube or conduit, and to make contact with them by means of a sliding connection, passing through a slot in the roadway. At the present time,

the conduit system is a thoroughly practical and reliable method, but it has only reached this stage, through a long series of experiments and failures.

Conduits were constructed at Buda-Pesth in 1881, at Blackpool in 1884, and, at about the same date, in America, so that experience with them has been, practically, as long as with the overhead trolley. But the early conduit were failures for three reasons. They were not strongly enough constructed to stand the ordinary heavy road traffic, and trouble with slot closures was frequent. The insulation of the bare conductors in the conduit was insufficient, and the drainage of the conduit was not properly considered. Costly experience has shown how to get over all these troubles, and, given a modern well-constructed conduit road, there is no engineering difficulty whatever in working and maintaining it, as effectively as any overhead line.

Cost of Conduit construction.—The great enemy to the general use of the conduit system is its prime cost. The construction of a tube, generally about 24 inches deep, by 16 inches wide, through the middle of the roadway, under each track, and with a slot narrow enough to prevent the wheels of vehicles from passing through, but wide enough to admit the plough or current collector, cannot be carried out except at heavy cost. The very parts of our cities where the overhead system would be objected to, are generally those parts where the greatest complication of underground pipes, etc., is to be found. The amount to be expended, in removing such obstructions, to make a clear passage for the conduit, is unknown, in any case, until the work is actually done.

Conduit construction, carried out on satisfactory engineering lines, costs between £13,000 and £16,000 per

mile of single track, or between £26,000 and £32,000 per mile of roadway, for track work and paving only, and exclusive of any distribution cables. Such a cost would be prohibitive, excepting where a very frequent service of cars could be maintained. The capital charges, on the road construction, are so heavy, that the only way to bring down the cost per car mile, is to increase the number of car miles, as much as possible, by working the lines for all they are worth.

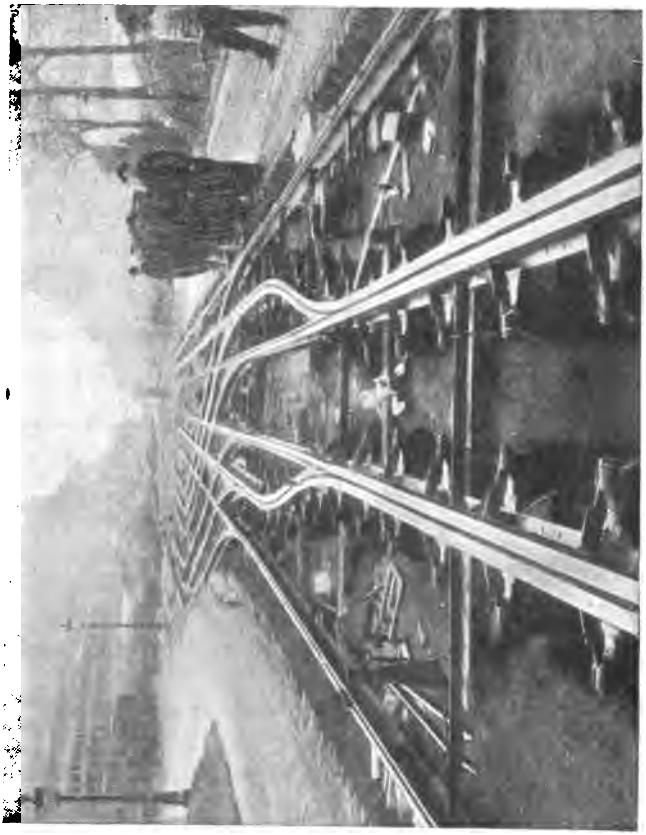
Conditions warranting use of Conduit.—In the Author's opinion, the adoption of the conduit is only justified under one or other of the following circumstances, viz. :—(1) When the traffic over the lines is so great, that the heavy fixed capital charges do not make any serious addition to the costs per car mile. This is a condition of things only met with in Metropolitan cities, and, after all, is no reason why the overhead system should not be used. (2) When the powers for the tramway can only be obtained on the condition that the conduit is used. (3) When the system of lines is so complicated, that the overhead construction becomes cumbersome and dangerous.

Both (2) and (3) are again controlled by (1), since, unless the traffic can be guaranteed, the line cannot pay, and had, therefore, better not be constructed.

Types of Conduit construction.—At the present time conduit roads are at work in New York, Washington, Paris, Berlin, Brussels, Vienna, Buda-Pesth, Lyons, Nice, Bordeaux, London, and Bournemouth. Two distinctive types of construction are in use, the one having the conduit immediately under one of the track rails, the groove in the track rail forming the slot, and the other with the conduit between the two rails, in the centre of the track. American practice is entirely centre slot construction,

while Continental practice is divided, the last three cities mentioned above having the centre slot, and the remainder the side slot system. Of the two lines now

Fig. 141.



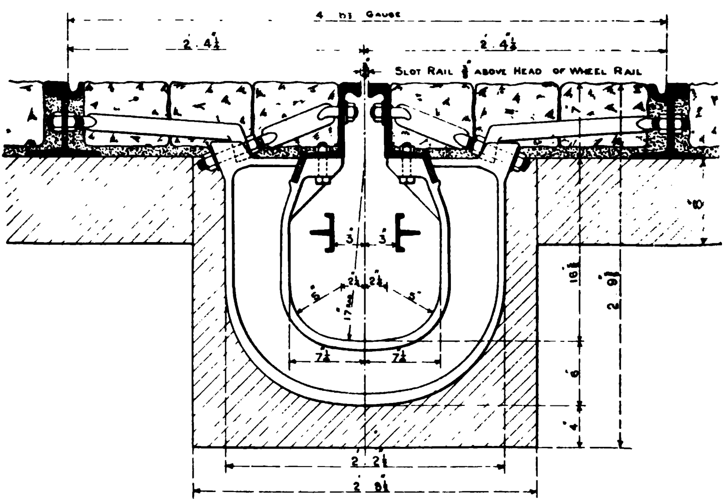
FROM SIDE SLOT TO CENTRE SLOT. PARIS.

working in England, the Bournemouth line is side slot, and the London line centre slot.

Each type of conduit has its advantages and disadvantages. From the point of view of the road surface,

the side slot is preferable to the centre slot, since the amount of metal on the surface is much less. But, while the centre slot can work efficiently, with an opening not greater than $\frac{3}{4}$ in. wide, the side slot has to be at least $1\frac{1}{4}$ in. wide, and often more, because it has to form the groove for the wheel flange as well. There is not much difficulty in using a $1\frac{1}{4}$ in. slot on a straight track, but, when it

Fig. 142.



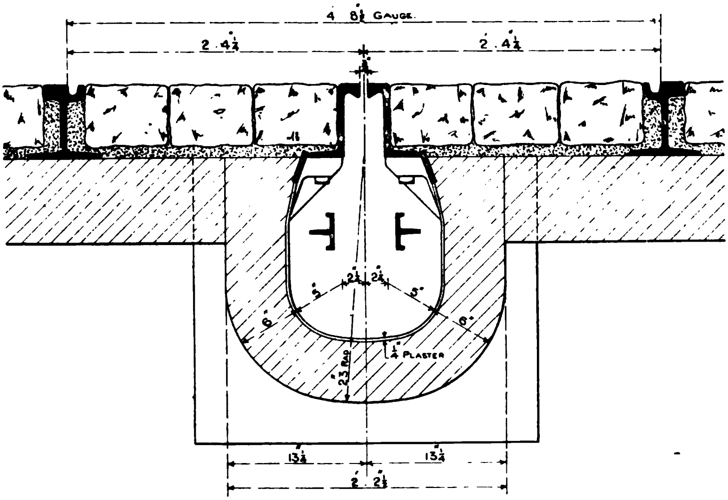
CROSS-SECTION OF CENTRE SLOT CONDUIT, AT YOKE. LONDON.

comes to points and crossings, the open gap becomes considerable, often amounting to nearly 3 inches. This is dangerous to ordinary traffic, as vehicles, with narrow wheels, are very liable to get caught. In order to avoid such large openings at the special work, and to get rid of the difficulties of using the same point for both the plough and the wheels, while retaining the general advantages of

the side slot, Mr. Connett, on the Paris and Bournemouth lines, diverted the side slot to the centre, immediately before the track point is reached. Fig. 141 illustrates a piece of line at Paris, where the diversion to the centre has been carried out.

Yokes and slot rails.—Whether the conduit be under the track rail, or between the two rails, its construction is very

Fig. 143.

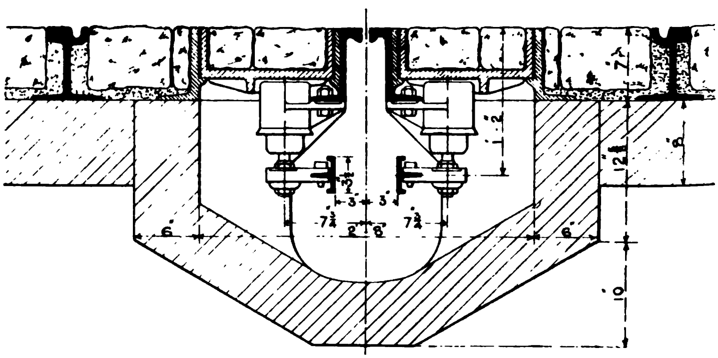


CROSS-SECTION OF CENTRE SLOT CONDUIT, BETWEEN YOKES. LONDON.

similar. Cast-iron U-shaped yokes are used, for the double purpose of carrying the slot rails, and for lining up the conduit. These yokes are placed from 3 ft. 9 in. to 5 ft. apart, and are embedded in concrete. The conduit itself is formed of concrete to the shape of the yoke, by means of collapsible timber centering, temporarily placed between the yokes. The thickness of the conduit walls is about 6

inches, and the concrete is carried right up to the underside of the slot rail. Fig. 142 shows a cross-section of a centre slot conduit at a yoke, Fig. 143 a cross-section between yokes, and Fig. 144 a cross-section through an insulator box. It will be seen that the slot rails are of Z section. The lower flange is bolted to the top of the yokes, the two slot rails being spaced the correct distance apart, which is adjusted by means of the tie-bars shown in Fig. 142.

Fig. 144.



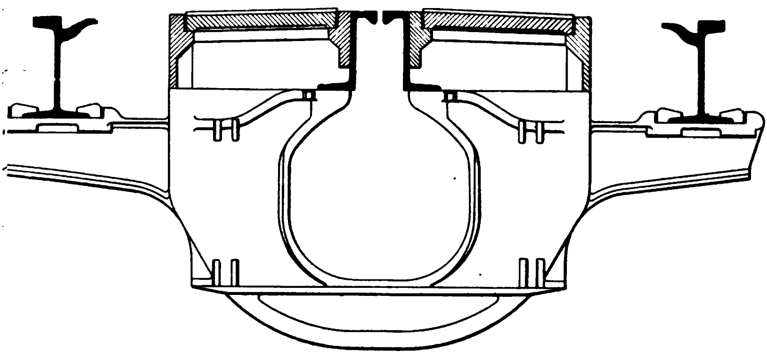
CROSS-SECTION OF CENTRE SLOT CONDUIT, AT INSULATOR BOX. LONDON.

The slot rails are made of steel, of a less hard quality than is usual for track rails. The figures, given above, show a section of the slot rail used for the London County Council conduit tramways. It weighs 60 lbs. per yard, is 7 inches deep, and is supplied in 30 feet lengths. The inner face of the slot rail is made with a drip edge, so that any rain or water, falling into the conduit, will drop clear of the conductor bars.

Extended yokes.—Figs. 142, 143 and 144 show a centre slot conduit, with the track rails carried upon a concrete

bed, in the ordinary manner. The American construction is of a slightly different type. Instead of the yokes being used merely for forming the conduit, and for supporting the slot rails, they are employed, in addition, for carrying the track rails, by means of an extended arm on either side. Such an extended yoke is shown in Fig. 145, which is a cross-section of one of the New York lines. Among experts, opinions differ as to the relative advantages of extended and simple yokes. Those with experience only

Fig. 145.



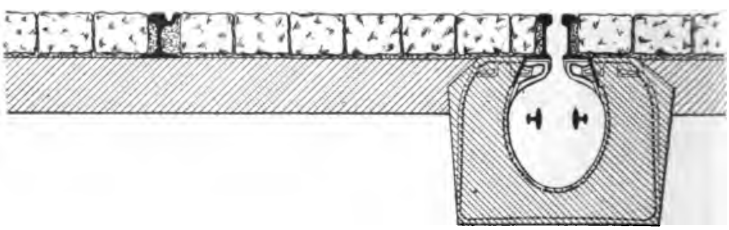
EXTENDED YOKE CONSTRUCTION. NEW YORK.

of American work, are strongly in favour of the extended yoke, while those who are familiar with the Continental side slot practice, consider that extended arms to the yokes are so much waste metal. From the point of view of the constructor, the extended yoke has the great advantage, that it forms a support for the track rails, and a ready means of alignment and setting up, before any of the filling in, or concreting, of the roadway is done. It is also claimed that the extended yoke forms a necessary

support for the track rail, and that it helps to keep the gauge of the track correct.

But, when the side slot conduit is used, no one considers it necessary to put a very long arm on one side of the yoke, to carry the farther track rail. It is usual to support this track rail on the concrete only, in the ordinary manner, and no trouble has been found in keeping the gauge of the track constant. A cross-section of a side slot conduit is given in Fig. 146, and it will readily be seen, that, if such a construction give good mechanical

Fig. 146.



CROSS-SECTION OF SIDE SLOT CONDUIT. BERLIN.

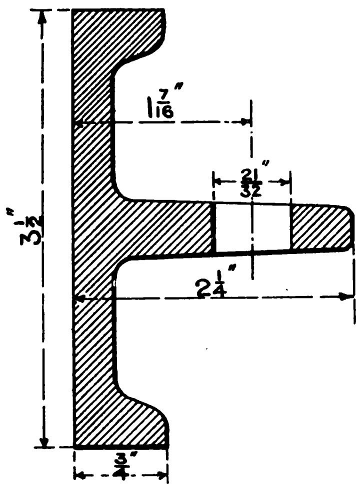
results, with the weight of the car carried upon one of the slot rails, there is absolutely no reason why extended arms should be necessary, when both track rails are independent of the conduit. In the Author's opinion, the only advantage, which the extended arm possesses, is the assistance it gives in setting out the work during construction, but, for this purpose, it is certainly not necessary that every yoke should have extended arms.

The shortest track rails in use are about 30 ft., and with yokes spaced 5 ft. apart, quite enough advantage would be derived, in lining up the track, if every third yoke were made with extended arms, and the intermediate

ones plain. Against this opinion must be set that of those engineers, who have had considerable experience with side slot construction, which is, that no advantage at all is obtained by the use of extended arms.

Rails for side slot Conduit.—It will be noticed, from Fig. 146, that the type of slot rail, used in the side slot construction, is quite different from that with the centre slot

Fig. 147.



CONDUCTOR TEE RAIL. L.C.C. TRAMWAYS.

construction. In the former case, the slot rail has to carry the wheels of the car, while, in the latter case, the ordinary road traffic only has to be provided for. The amount of metal, on the surface of the road, is greater with the side slot system, than with the ordinary plain track construction for the overhead system, but it is less than with the centre slot system.

Conductor tee rails.—Wherever conduits have been used,

advantage has always been taken of the fact, that it is as easy to insulate both the positive and the negative conductors, as to insulate only one, and to use the rails as a return. All troubles, due to a rail return, are thus avoided, and no bonding of the track rails is required. The conductors in the conduit are now always made of a very soft steel, having as little carbon and manganese as possible. This is in order to obtain a high electrical conductivity, and some makers will guarantee as much as 99% of pure iron. The shape and dimensions of the conductor tee, used on the London County Council lines, are shown in Fig. 147. This may be taken as characteristic of those used on other conduit lines, but the relative dimensions vary somewhat. In the present case, the rails weigh 22 lbs. per yard, and are supplied in 30 ft. lengths. Although no bonding is required for the track rails, yet the conductor tees have to be bonded instead.

Insulators.—The conductors are supported, at intervals of 15 ft., by means of special insulators, which are generally carried from the flange of the slot rails, on either side. Fig. 144 shows an insulator in position, and the general features will be evident. The main body is of porcelain, with a single petticoat, and the steel bolt, which carries the bracket for the conductor tee, is cemented into the centre. The insulator itself is protected by an outer cast-iron shell, by an extension of which it is bolted to the slot rail. On some of the earlier lines, the insulators were carried on pillars, from the bottom of the conduit, but it was found exceedingly difficult to keep them clean and dry, on account of the rapid accumulation of dirt, and their use was soon abandoned.

Insulator boxes.—On the New York lines, the insulators are contained in a cast-iron box, formed in the extended

arms of every third yoke. To the top of this box a frame is bolted, which carries the road cover, immediately over the insulator. On other lines, a cavity, for the insulator, is formed in the concrete, and the frame for the box cover is bolted to the slot rail. In most cases, insulator box covers are made flush with the roadway, so that the insulators can be got at at any time, for the purpose of cleaning or repairs. These road boxes, coming, as they do, in pairs every 15 ft., are apt to become a source of trouble, not only on account of their liability to stand high, as the paving wears, but also because of the difficulty of properly securing the paving in such a small iron frame, the cover generally measuring not more than 12 in. square.

On some of the Continental lines, notably in Paris and Berlin, the insulator box covers are kept well below the surface of the road, and the paving is carried right over them. The engineers in charge of those lines say, that they seldom have to inspect any of the insulators, and that, when they do, it is preferable to break up the paving at that point, than to be troubled with flush road boxes all the time. Certainly the appearance of a road, without the boxes, is much superior to a road with them.

Positions of Conductor tees.—Conductor tees are usually suspended, at a depth of about 14 in. to 15 in. from the surface of the roadway, and about 6 in. apart. They are, therefore, well to the side of the slot, and are free from a large proportion of the dirt, which may fall through. It is very essential that the distance between the conductor tees should be kept exact, as, although the plough contacts are carried on springs, it is quite easy for bad contact to be made. The bracket, carrying the conductor tee from the insulator bolt, is, therefore, generally provided with an eccentric nut adjustment.

Fig. 149.—SPECIAL WORK AT CROSSING OF TWO CENTRE SLOT CONDUIT ROADS.

Special work.—It is in the character of the special work, that one of the great differences, between the road construction for overhead lines and for conduit lines, becomes apparent. In the first place, the slot, at the junction of two lines, has to be provided with a tongue point, similar to the track rail, and the crossings are not only for track rail across track rail, but also for slot across slot, and for slot across track rail. The mere fact that the two conduits themselves come together at a junction, and merge into one, will make it evident, that the cavity under the road must be very considerable at such places. The ordinary type of cast-iron yoke has been described, but, at special work, quite a complicated structure of special yokes, gussets, etc., has to be used, both in order to form the conduit, and to carry the road work above.

Since the conduits have to be kept at their full dimensions, under each slot, at a junction, they will run together much sooner than the slots, because of their greater width. The slot point will, therefore, be considerably overhung, sometimes for several feet, and the strength of the special work has to be proportioned in consequence. In Figs. 148 and 149 are shown views of special work at an ordinary junction, and a track crossing, from which the complication and expense will be self-evident.

The special work adds, considerably, to the cost of a conduit line, and this often amounts to three times as much as for similar work for an ordinary track.

The slot points, and the track points, at any junction, must, of course, be worked together, in order that the plough and the car may each take the proper track. The plough is guided merely by the slot rail, and is, therefore, dependent upon the points for its correct position. It is customary to set the slot points, at a road bifurcation, a

little after the track points, so that the car itself has taken the correct road, before the plough meets the points. It is always necessary to enter points with care, as, should a plough take the wrong road, it may be possible to stop the car, and reverse it, before much harm has been done. The plough carrier, which is mentioned later, should be made with open ends, so that the plough, if it take the wrong track, can travel the full width of the car, and then fall off, into the roadway, clear of the car.

One of the difficulties in conduit work, which is not experienced in the overhead system, is the long break, which must be made, in the conductors, at all track junctions and crossings. As a passage for the plough must be left in each direction, and as both positive and negative conductors are employed, the break becomes considerable, often amounting to 12 ft. or more. This means that the car must coast over these dead points, and, if the driver should bring it to a standstill, with the plough in such a position, the car cannot again be moved without external help. With care, however, little or no trouble is experienced, the only annoyance being that the car lamps go out, for quite an appreciable interval, as the car passes these places.

Changing polarity of Conductor tees.—The conductor bars, in a conduit system, have to be divided into half-mile sections, in a similar manner to the overhead conductors, in the trolley system, in order to meet the requirements of the Board of Trade. It is usual to make the space between the corresponding conductor bars, at such sections, about 2 feet in length. This is done so that it may be possible to change the polarity of any section, without danger of interference from its neighbour, and also that the plough may be removed at such places.

This change of polarity is quite a feature of the conduit system. With the overhead system, the overhead wire is always positive, and the track rails negative, but, in the conduit system, two insulated conductors are used. If a leak take place on either conductor of a section, or on the plough of a car, it would make no difference, so long as a second leak did not take place on the opposite conductor. Should this happen, a short circuit would result. But, by feeding each half-mile section by independent cables, from the power station, or from a sub-station, it is possible to change the polarity of the conductors, in any section, as may be desired.

When a second leak takes place on *another* section, and on the opposite conductor to the first leak, the polarity of that section is at once reversed by the switchgear, so as to bring both leaks on one side of the system. Special leakage indicators are arranged on the switchboards, so that the attendants can always ascertain the condition of the various sections, and, by means of reversals, the lines can often be kept working, until it is convenient to send out to locate and remove the fault. Should a leakage occur on both conductors of the *same* section, reversing the polarity would, of course, be useless, and, if the leak be a bad one, the section must be cut off entirely, until the fault be remedied.

Conductor tees at Special Work.—In arranging the conductor tees, great care must be taken, at special work, in order that there may be no likelihood of short circuiting, when the car passes from one line to another. In Fig. 150 is shown a diagram of conductor tees, at a typical junction. It will be noticed that the polarity is not changed, so far as the car is concerned, whichever line it is running on. This is a point to watch, since, if there be a

leak, say, on the positive side of the plough, and the conductor bars of that section have been reversed to counter-

Fig. 150.

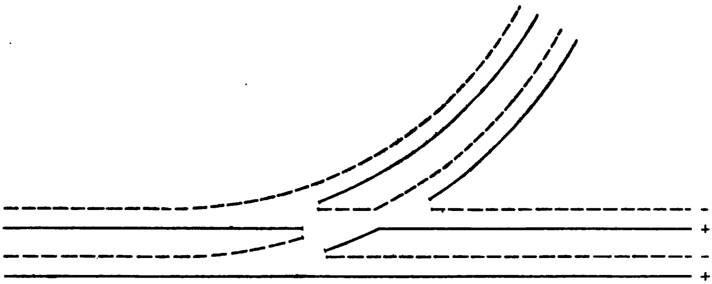
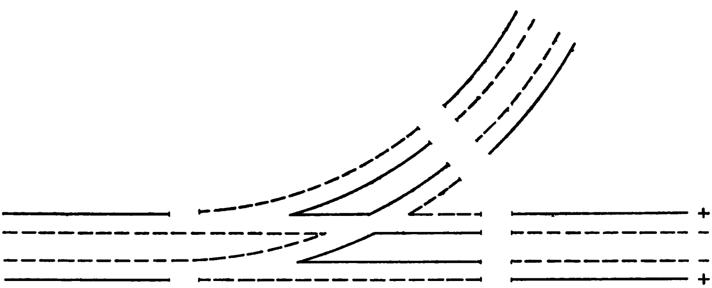


DIAGRAM OF CONDUCTOR TEES AT TRACK JUNCTION.

act it, should such a car run through a junction, where the polarity is reversed for a few feet, on account of the arrange-

Fig. 151.



INCORRECT ARRANGEMENT OF CONDUCTOR TEES.

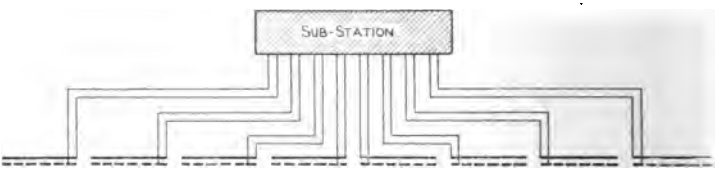
ment of the conductor bars, such as is shown in Fig. 151, then a short circuit would result.

Sectional Switch pillars.—Section switch pillars must be employed, at each half-mile section, as in the case of over-

head construction, and there should be a distinct pair of cables from the station to each half-mile. There are several methods of feeding the conductor bars, but, in the Author's opinion, the most satisfactory way is to let each pair of cables feed, ordinarily, in one direction only, and at one point only, as is indicated in Fig. 152.

Switch boxes should be so arranged that it is possible to feed in either or both directions, or that the two half-mile sections can be joined through, without connecting up the feeders. But, as the polarity of either section can be

Fig. 152.



METHOD OF FEEDING CONDUCTOR TEES EVERY HALF-MILE.

reversed at will, at the station, it may happen that the switches, in the switch pillar, which are normally at the same potential, suddenly have the full line potential of 550 volts between them. It thus becomes a problem to design a switch arrangement, which will be safe for an inexperienced man to operate under all conditions.

It will be seen, that if the switches are set so that the feeder is feeding, say, the left-hand road, while the right-hand road is fed from the next switch pillar, should any person close the switches, in the first pillar, which connect the right-hand road up, it may be safe, or it may be a short circuit, depending entirely upon the way in which the attendant at the station has the polarity of the two sections arranged.

Examples of Sectional Switches.—The switching arrangements at the feeder pillars, which have been got out by the Author, for use on the London County Council conduit lines, are shown, in diagram, in Fig. 153.

On the front of the panel there are arranged eight

Fig. 153.

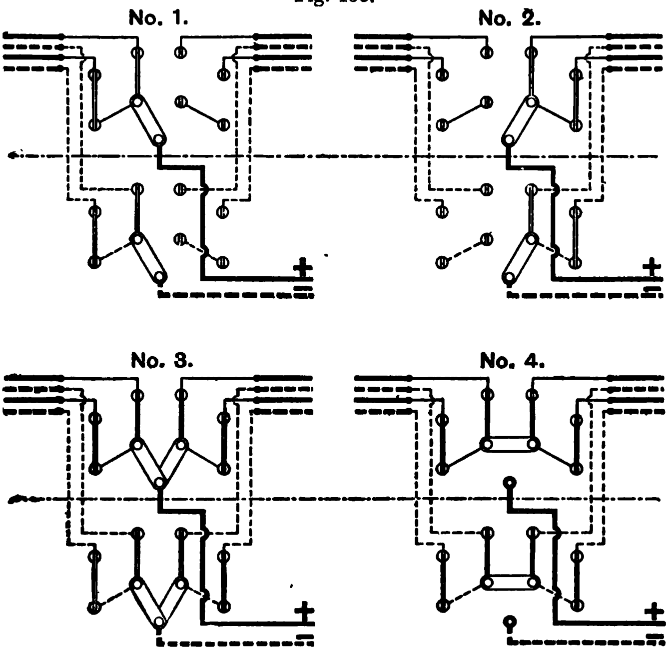


DIAGRAM OF L.C.C. SECTIONAL FEEDER SWITCHES.

switches, two for each left-hand track, and two for each right-hand track. Any person, operating these switches, can only switch on or off either of the conductor bars. The feeder cables are brought up at the back of the panel, which is provided with a separate door. By means of special connecting links, and a triangular arrangement of

terminals, it is possible to connect up the feeder and the switches, in any desired manner.

Fig. 153 shows the four positions which are possible, viz.:—(1) With the feeder feeding the left-hand tracks only. (2) With the feeder feeding the right-hand tracks only. (3) With the feeder feeding both sets of tracks. (4) With the feeder disconnected, and the tracks joined through.

The car driver, or conductor, or any other inexperienced person, who may have to operate the switches, because of an accident, can only switch the conductor bars on or off, and it will be seen, from the connections, that if he operate the wrong switch, he can do no serious harm. The changes with the links, which determine the whole thing, can only be carried out by an expert, sent out from the station, and, therefore, with the full knowledge of the sections, before any changes are made.

Motors and Car wiring for Conduit Lines.—One result of the possible reversal of the polarity of the conductor tees, is that the car motors must be insulated for the full potential above earth, both on the field coils and the armatures. With the trolley system, the field coils of the motors are usually connected to the motor cases, and, therefore, to the rails, and it is not possible to have more than a few volts difference of potential between them and earth. But, on the conduit system, the field coils may have to stand the full pressure above earth, and, although, if the motor be properly made, there should be no trouble about this, it is well to inform the motor builders of the condition.

On trolley lines, as may be seen from Fig. 68, an automatic circuit breaker is used at one end of the car, and a canopy switch at the other, both being in series between the trolley and the controllers, while the other side of the motors is earthed, as mentioned above. Opening either

the circuit breaker, or the switch, will therefore effectually take pressure off the car wiring.

But, on the conduit system, there must be a circuit breaker and a canopy switch at each end of the car. The breaker at each end is joined in series with the switch at the other, and the one pair is connected on the (positive) side of the plough, while the other pair is on the (negative) side. Whatever the polarity of the conductor tees, it is thus possible to cut current entirely off, from either end of the car.

Similarly the lighting circuits must be provided with switches and fuses on both poles, as, with single pole switches, it would not be possible to cut off a circuit under all circumstances.

Ploughs.—Perhaps the most important item, on any conduit line, is that of the car plough. The plough is the device by which the current is collected from the conductor tees in the conduit, and carried, through the narrow slot, up to the motors. It is no easy matter to design an efficient plough. Not only are the electrical conditions very onerous, as two conductors, with 500 volts between them, have to be brought up through a $\frac{3}{4}$ in. slot, but the mechanical conditions are quite as troublesome.

The plough has to be very strong, in order to stand the wear and tear of travelling at any speed, up to sixteen or twenty miles an hour, but it must not be so strong that it will injure the conductor bars, in case of an accident. It has to work under all kinds of weather conditions, it is frequently covered with mud and dirt, and it has to pass through a narrow slot, with two live conductors in its centre. Some of the Continental ploughs are very light and flimsy structures, but those in use in this country, and in New York, Washington, and Paris, are much

more mechanically designed. Probably the best type is that which has soft cast-iron rubbing shoes, which are pressed against the vertical faces of the conductor bars, by semi-elliptical springs placed horizontally. This type of plough is shown in Fig. 154.

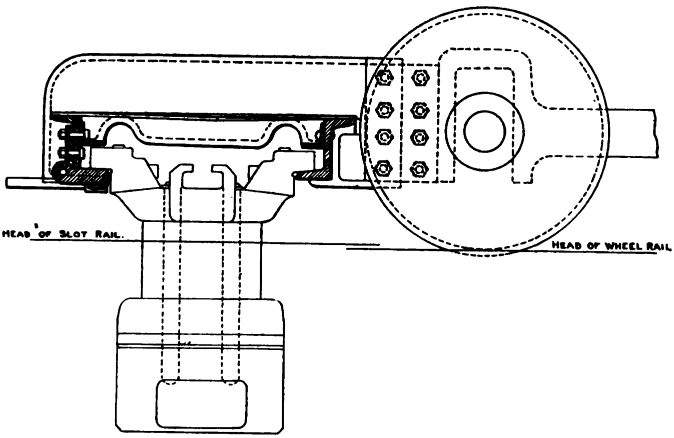
Fig. 154.

CAR PLOUGH.

The sides of the plough are protected by steel faces, which take the wear, where it passes through the slot, and the conductors, which pass up between them, consist of copper tape insulated with mica, etc. They are connected to the rubbing shoes by flexible copper fuses.

These fuses are only intended to act in the event of a short circuit within the plough itself, and they should therefore be set to blow with a current at least 50 % higher than the car circuit breakers. Great care must be taken to ensure good contact between the fuses and the plough shoes, or premature blowing of the fuses will result, and serious inconvenience may be caused. The top of the plough is

Fig. 155.



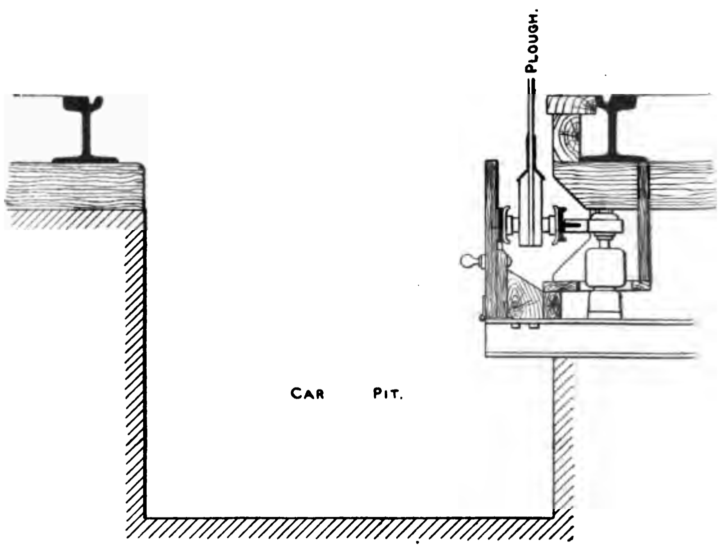
PLOUGH CARRIER FOR BOGIE TRUCK.

formed, as shown in Fig. 154, so that it may slide, to and fro, in a horizontal position, under the car.

Plough Carriers.—The plough carrier generally consists of a steel frame, which is carried across the truck. In the case of a maximum traction truck, the plough carrier is placed on an extension of the truck frame, at the extremity of the axle boxes of the pony wheel. On an ordinary four-wheeled truck, the plough carrier takes a mid-way position between the motors. Fig. 155 shows a good form of plough carrier, for a bogie truck.

Small angle bars are fixed on the top side of the carrier, to keep the plough in position, when the car is running. The tendency of the plough is to rise, and these small bars prevent any such motion. The plough must always be left free to travel sideways, and the plough carriers should be long enough to allow the plough to come

Fig. 156.



SIDE SLOT CONSTRUCTION IN CAR PIT.

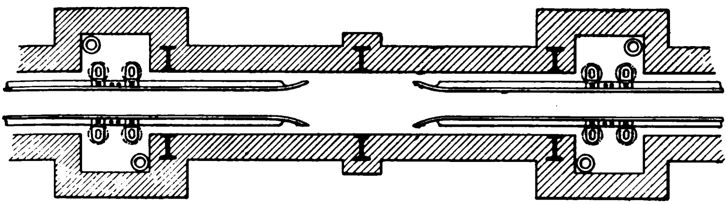
right over to either side, and outside the line of the car wheels, before it falls off.

Such a wide travel has several advantages. In the case of the car and the plough taking different roads, at a junction, the plough will fall clear of the car without getting damaged, and, in the car shed, it is possible to use a side slot in the pits, thus keeping the pits free for the use

of the men. A simple form of construction, for such a side slot in the car pit, is shown in Fig. 156. It is exceedingly convenient to be able to move the cars anywhere in the sheds, by means of the plough, and the ordinary conductor bars, in the arrangement shown, answer admirably for the purpose.

Plough hatches.—To remove the plough from the conduit, it is necessary to fix special hatches in the slot rails. These consist of removable plates, about 3 feet long, and 4 inches wide, which can be lifted out of place by hand, thus leaving a large opening immediately over

Fig. 157.



ARRANGEMENT OF TEE CONDUCTORS AT SECTION INSULATOR.

the conduit. The conductor bars are broken at a plough hatch, when this occurs at a section insulator, and Fig. 157 shows the arrangement in plan. When the covers of a plough hatch are removed at such a place, there is sufficient width to allow the plough to be turned diagonally, so that it slips off the plough carrier. It can then be taken out of the conduit, and removed.

A plough hatch should always be provided at each half-mile section, and also close to any special work, so that, should a plough fall from the carrier, through taking the wrong points, it can be slipped along the conduit, by

hand, to the plough hatch, and removed altogether. Should the plough fall from the carrier under the car, except at an open plough hatch, it could not pass through the slot, and the upper portion, being several inches high, may foul the motors or the gear cases, and considerable damage may result.

To remove a plough in the car shed, using a side conduit, such as is shown in Fig. 156, the side of the wooden casing is made in sections, so that it will fall back on hinges. The outer conductor bar is also divided, and comes away with the side of the casing, so that a man, standing in the pit, can examine the plough or remove it from the carrier.

Combined Conduit and Trolley systems.—In several instances, the conduit system has been used for certain parts of a town, with the overhead system in other parts. The cars have, therefore, to be provided with both a plough and a trolley. When running over the conduit section, the trolley is tied down to the roof of the car, and, when running over the trolley section, the plough is lifted out of the conduit.

With the exception of Bournemouth, such a combined system has only been used on lines running single-deck cars, and, with such cars, there is no difficulty with the trolley arm, when tied down, as it will lie close to the car roof. Double-deck cars are at a disadvantage in this respect, as it is difficult to tie a trolley arm down, without making it inconvenient for the passengers who may be on the roof.

Plough lifting devices.—At the point of junction of the overhead and the conduit, special means have to be provided for removing the plough. It is quite an easy matter to put the trolley wheel on the wire, or to take it off, by means of the ordinary trolley rope. But the plough

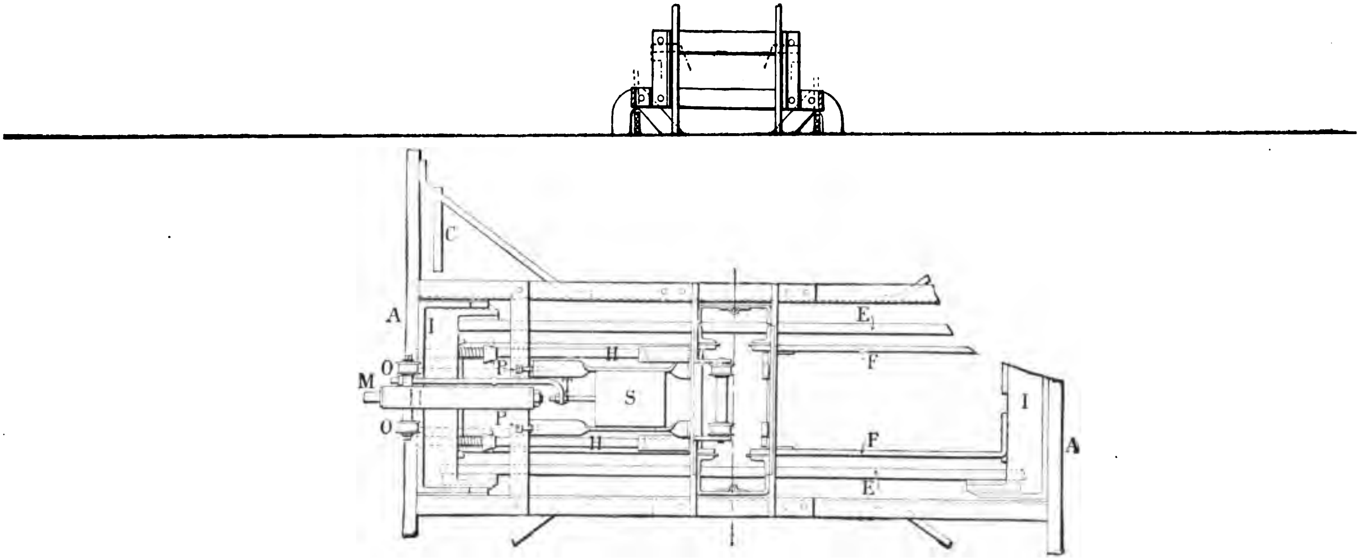
Fig. 149.—SPECIAL WORK AT CROSSING OF TWO CENTRE SLOT CONDUIT ROADS.

In Vienna, and Berlin, where a much more primitive type of plough is used, the plough can be lifted up through the wide side slot, without the use of any special plough box. The contact faces of the plough consist of flappers, which will close in, as the plough is passed through the slot, and rest on the top of the conductor bars, at an angle of about 45° from the horizontal, when the plough is in position. Such a plough is weak, both mechanically and electrically.

In Vienna, the plough is wound up, out of the slot, by the motorman, who turns a handle fixed on the platform, and, in Berlin, the plough is lifted out of the slot by hand. In the latter case, the plough is not carried under the car, but at the end of a radial arm, which projects under the rear platform of the car. The head of the plough rests on the slot rails, and, when the arm is lifted up, the contact is automatically broken. A view of the car, at the changing place in Berlin, is shown is Fig. 158. The operation of removing the plough can be clearly seen. Both in Vienna, and Berlin, the whole operation of changing takes only about 10 seconds.

Probably the best arrangement, for raising and lowering the plough, is that originally devised by Mr. Connett, for use on the Paris, Bournemouth, and London tramways. The plough hatch has a special arrangement of covers, operated by a lever, which can be inserted in a socket, close to the track. The covers can then be raised or lowered after the car is standing in position, at the stopping place. The plough carrier has a device, which, while permitting the full sliding movement of the plough across the width of the car, yet enables it to be lifted entirely out of the conduit, when the covers of the plough hatch are moved.

Fig. 159.



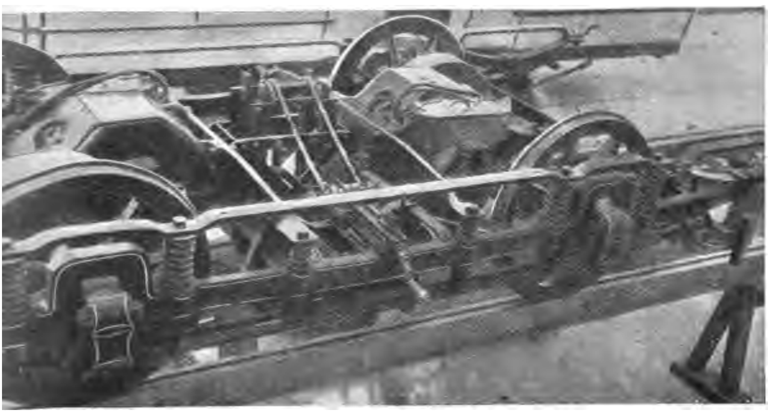
PLAN.

PLOUGH LIFTING DEVICE. PARIS.

To face page 318.

A special carriage is fixed in the centre of the car, which can be raised or lowered, by means of a fixed screw, a travelling block, and link chains running over rollers. The square end of the lifting screw is accessible, at the side of the car, and when the plough is on that part of the carrier immediately within the lifting carriage, it can be lifted bodily up, by turning the screw. In Fig. 159 are given the side elevation, the front elevation,

Fig. 160.



TRUCK WITH PLOUGH LIFTING DEVICE. PARIS.

and the plan of this device, as used in Paris, and, in Fig. 160, a view of a car truck, equipped with this apparatus, is shown.

The Paris lines use a side slot, but the conduit is diverted to the centre, at the changing place, and so the lifting device is centrally placed. Flexible connecting cables to the plough enable it to have full freedom of movement, on its carrier, from one side of the car to the other. The changing from the plough to the

trolley, and *vice versâ*, by this method, also occupies about 10 seconds. The plough hatch is opened, and the plough lifted out, by a pointsman, while the conductor attends to the trolley. The controller is provided with a special switch, which puts either the trolley, or the plough, into action, and the plough lifting device is so arranged, that it can only be worked by the car controller handle, which ensures that the controller is in the off position, before the plough is either raised or lowered.

Earthing on combined systems.—All conduit systems work with two insulated conductors, and the rails are not used as any part of the circuit. But, when the overhead system is used, the rails are made use of, and, in order to prevent the earthing of either conductor on the conduit section of a mixed system, the overhead portion of the system should be supplied by special machines and circuits. This is somewhat of a disadvantage, but, if the two sections be of a reasonable size, no trouble should be experienced in doing this.

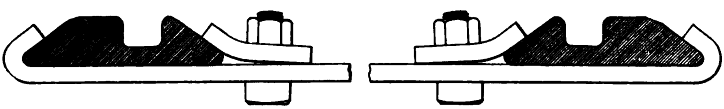
Constructing a Conduit line.—The construction of a conduit line entails a large amount of interference with the ordinary road traffic, considerably more so than in the case of an overhead line, since the work is very much greater, and, therefore, takes a much longer time. Of course, the employment of more men would lessen this disadvantage, but very long lengths of road must be open at one time, in order to carry out the various parts of the work in their correct sequence. In any case, the special work cannot be done nearly so quickly as ordinary special work.

A great deal will depend upon whether the line is entirely a new one, or whether it is an existing line being

reconstructed. In the latter case, the tramway service has to be maintained, and this means a considerable interference with the work. It is usual, in such cases, to lay down lengths of temporary track, with temporary points, etc., in order that cars may be diverted round that portion of the road, where the work is going on.

Such temporary track must be of a kind which will allow ordinary traffic to pass over it, and probably the best kind is that shown in Fig. 161. It consists of a special flat rail, of triangular section, which lies directly upon the ground, and is connected across to its fellow rail by means of flat tie-bars. Temporary track, of this kind, is often necessary, even when laying ordinary lines,

Fig. 161.



TEMPORARY TRACK.

but, on account of the nature of conduit construction, much greater lengths of the road must be open, and hence the amount of temporary track is much greater.

The conversion of a horse line, to a conduit line, entails more work than building a new line, since not only have the old rails to be removed, but the greater part of the old concrete bed has to be cut away, to make a channel for the conduit. When yokes without extended arms are used, such as the one shown in Fig. 142, the excavation for the conduit is first made, with small depressions under where the yokes will come. The yokes are then placed roughly in the trench, and the slot rails are bolted to them. By means of temporary beams, or

Fig. 162.

CENTRE SLOT CONDUIT CONSTRUCTION. LONDON.

baulks of timber, the slot rails are blocked up into their correct position, with the yokes hanging from them, as shown in Fig. 162. Concrete is then filled in under the yokes, so as to make a firm bedding.

Collapsible wooden centering, in lengths sufficient to reach from yoke to yoke, is then placed in position, to form the contour of the conduit. Concrete is next filled into the trench, and rammed in hard, round the wooden centering and the sides of the yokes, this forming the concrete tube. Small iron strips, called paving strips, about 3 in. wide, are carried on supporting lugs, at the top of the yokes, in order to form a close joint with the flange of the slot rail. These strips may be seen in Figs. 142 and 143. If the insulators are to be carried between the yokes, cavities must be formed in the sides of the concrete tube, by means of wooden boxes, during its construction.

While the concrete tube is setting, the ordinary bed for the track rail is put down, consisting of about 8 in. of concrete. The rails are then laid in position, and the tie-bars, between them and the yokes and the slot rails, are fixed, and the gauge of the track is adjusted. Very fine concrete is then rammed under the flanges of the track rails, in order to give them a firm and level bedding. It is very necessary that this part of the work should be most carefully done, so as to ensure a solid bed entirely across the full width of the rail.

Those parts of the concrete tube, which are occupied by the temporary wooden supports under the slot rails, have to be made good when the other portions are set, and the timber removed. Before the paving is laid down, the distance between the slot rails is carefully adjusted, by means of the tie-bars and the bolts holding the slot rails

to the yokes, and the iron frames of the insulator boxes are placed in position, over the insulator pits. The timber centering, used for the concrete tube, can be removed through the conduit, since it is collapsible. If care be taken with the mixing and ramming of the concrete, the interior of the conduit is left quite smooth enough for ordinary purposes, when the centering is taken away.

The insulators can be placed in position, at any time after the centering has been removed, and then the work of inserting the conductor tees is taken in hand. At intervals, a length of slot rail is left out, for the time being, in order to provide a space, through which the conductor tee can be passed. Special carrying hooks, with rollers running on the slot rail, are used, for carrying the conductor tees along the conduit, to their proper place. The tees are then bolted up to the insulator brackets, and are adjusted, both for depth, and for distances apart.

Before the conductor tees are inserted in the conduit, holes at either end are made, for the copper bonds, which connect the various lengths together, and one end of the bond is fixed to the tee. When the tee is in position, the other end of the bond is inserted in the end of the next tee, access being obtained through the insulator box, and a special hydraulic riveter is employed to finish the bond off. Joints in the conductor tees should always come at the insulator boxes.

To insert the conductor tees at curves, they must first be bent to the exact radius, and a slot rail must be left out at the beginning of the curve, in each case. When all the conductor tees are in position, the remaining slot rails can be put into place, and the paving of the track finished off.

In constructing a conduit road, where yokes with ex-

tended arms are used, the operations are very similar. The excavations for the yokes are, of course, carried across the track, and the track rails are set in position, on the yokes, at the same time as the slot rails, and the whole of the concreting is carried out, practically at one operation. As the track rails are carried upon the yokes, the depth

Fig. 163.

CENTRE SLOT CONDUIT CONSTRUCTION. NEW YORK.

of concrete, under them, is not usually so great, as when the rails are carried only upon the concrete. Fig. 163 shows a portion of a conduit road under construction in 7th Avenue, New York, where extended yokes are used.

Draining the Conduit.—One of the most important points, in conduit construction, is to see that the draining facilities

are perfect. It may be said that the success of the road depends, almost entirely, upon it being possible to maintain it in a clean and dry condition. To ensure this, large sump pits are built at distances averaging about 120 ft. apart, and into these pits the two conduits are drained.

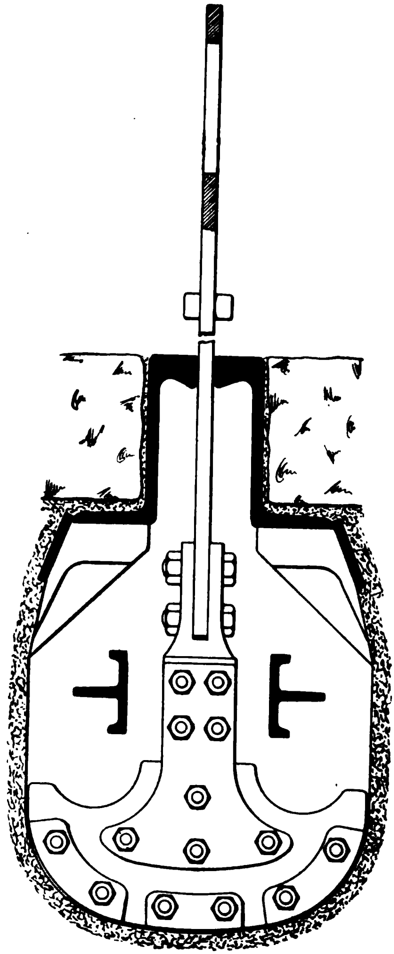
The pits themselves are connected to the nearest sewer. The connecting pipes must, in all cases, be large, so that it is not possible for them to become choked up, in any way. When the road has a natural fall, the drainage is carried out with ease, since any water, which may enter the conduit, at once flows into the sump pits. But, when the road is level, there is much more liability for mud and water to accumulate, at the bottom of the conduit. It is, therefore, necessary to clean out a conduit at very frequent intervals.

Cleaning the Conduit.—In New York, this operation is carried out, practically every night, and the success, which has attended the New York lines, must be attributed, in no small degree, to the care which is taken to keep the conduit clean. In Washington, the cleaning is done once every few months, with the result that the condition of the Washington conduits is not to be compared with those in New York.

It has been suggested, that a ready way of cleaning a conduit, would be to flush it with water, and, under certain conditions, this may be necessary, as, for example, when the mud or dirt had accumulated to such an extent, as to make it impossible to remove it by mechanical means. The method employed in New York is to use a scraper, made of thick indiarubber, shaped to the contour of the conduit, and to draw it through the conduit, by means of a small horse wagon. This scraper is shown in

Fig. 164, and it would appear to be most effective in its operation. The scraper is about 2 in. thick, and has, therefore, to be inserted in the conduit at a plough hatch. The cost of cleaning the New York conduit is given at 0·055*d.* per car mile.

Fig. 164.



SCRAPER FOR CLEANING CONDUIT.

Cost of operating.—The cost of operating a conduit line is the same, for the electrical power, as for the overhead system, but the cost of maintenance will be slightly greater. The ploughs need continual repairs, and over-hauling, and the special work will also cost more to keep up. The cost of cleaning the conduit is, of course, an expense which an overhead line has not to meet. In Brussels, where the combined overhead and conduit

system is at work, the figures for the two have been very carefully kept, and go to show, that the conduit line costs about 0·3*d*. per car mile, more than the overhead line. Figures for English practice are not available, at the present time, but, within the next few years, the experience gained on the conduit lines, in London and Bournemouth, will go far to assist in making reliable comparisons between the two systems.

CHAPTER XI.

SURFACE CONTACT SYSTEMS.

General Principles — The Claret-Vuilleumier System — The Schuckert System — Short-circuiting Skate — The Diatto System — The Lorain System—The Dolter System—Magnetized Skates—Stud Switches *v.* Multiple Switch-boxes — The Kingsland System — Insulated Rail Crossings—Cost of Surface Contact Systems.

General Principles.—Recognizing the æsthetic objections to overhead wires on the one hand, and the cost of the conduit system on the other, many attempts have been made to devise a system, which should be free from the disadvantages just named. Surface contact systems are the result, but, while almost perfect in theory, they are most difficult to design and work satisfactorily in practice.

All surface contact systems employ a row of iron or steel studs, measuring some few inches in diameter, and projecting about half-an-inch above the surface of the roadway, between the two rails of the track. These studs are placed from 10 ft. to 15 ft. apart, depending upon the minimum length of car which has to run over the road. A long contact bar, or skate, is fixed under the car, in such a position that it will rub on the studs, as the car travels along, and so conduct the electricity from the studs to the motors. The rails are generally used for the return circuit, as in the overhead system.

To make such a system as this a success, or even to make it possible for it to be used at all in a public roadway, it is necessary that only those contact studs, which are immediately under the car, at any instant, should be alive. This fundamental principle involves the use of an automatic switch for every stud, which makes the stud alive when the car is over it, and disconnects the stud from the circuit the instant the car has passed over it. All surface contact systems work upon this general principle, but we may divide them into two chief classes, according to the position of the automatic switch. The details of the apparatus, of course, vary considerably in every case.

In the one class may be placed all those surface contact systems, which employ a switch placed somewhere away from the contact studs, generally in the roadway or under the footpath. In the other class may be placed those which have the switch contained in a receptacle, immediately underneath the contact stud, of which it forms practically a part. In the large majority of cases, the automatic switches are worked electrically, either by means of the line current, or by means of a battery carried on the car. In one or two instances mechanical devices have been proposed, but, up to the present, none of these are in actual operation.

Surface contact systems are now used in Paris, Tours, Monaco, and Wolverhampton, and, for several years, a line was worked successfully in Munich. These various lines have demonstrated that it is perfectly practicable to work tramways by means of contact studs, but they have also shown the disadvantages inherent to such a system. Practically all the difficulties have arisen at the switches.

Probably the best way to explain the various features of

the surface contact systems, will be to give a brief description of those which are working at the present time, or have been working within a recent date. We will first consider those systems which have the contact switches independent of the contact studs.

The Claret-Vuilleumier System.—One of the first surface contact systems, with the switches distinct from the studs, was shown at Lyons in 1894, and was put into practical use in Paris in 1896. This was the invention of Messrs. Claret and Vuilleumier. Groups of twenty contact studs, in the roadway, were connected, by separate cables, to distributing switches, placed in manholes at intervals along the line. The contact pieces, in the distributer box, were arranged in a circle, and were connected in their correct order with the road studs. Four contact blocks, which were mechanically coupled, but electrically insulated, were placed upon a central pivot, so that they could revolve around the circle of contact pieces, in the distributer box, and thus make contact with one or the other of the studs.

The length of the skate, under the car, was such that at least one contact block on the road was always covered. By means of an electrical mechanism, within the distributer box, the contact arms were moved round, at the same rate as the car moved from stud to stud. The current from the stud, with which the car skate was in contact, and with which one of the contact arms of the switch was also in connection, moved the switch arms forward one stud, so that the next stud, in advance of the car, was made alive, in readiness for the skate, immediately it touched it.

In moving round, the contact switch, of course, made the last stud dead. Therefore, if the switch worked

properly, not more than two or three studs could be alive at any time, and those immediately under the car, but there was always the danger of the failure of the mechanism, and so studs could be left alive, which were not covered by a car.

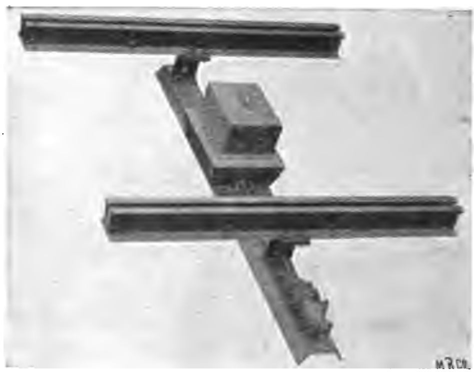
It was not possible, by this system, to have two cars nearer together than the number of studs controlled by any distributer box, and, as a result of this, if any driver ran his car, by momentum, into the next section, before the car in front had left it, he could not obtain any current. The car, therefore, had to stand still, and could not proceed until the driver had gone to the distributer box, and had turned the switch round, by hand, to the contact corresponding to the stud over which his car was standing. The details of this apparatus were worked out with great ingenuity, but the system was too complicated, and too unreliable, to become a practical success.

The Schuckert System.—Probably the best surface contact system, employing the switches grouped together, is that of the Schuckert Co., of Nurnberg. This system worked successfully in Munich from 1899 to 1901, in a part of the city where the trolley wire was prohibited, and was removed, not because of any difficulties in the working, but because the company, operating the lines, obtained permission from the city authorities to use the overhead system throughout, which meant a saving in the cost of equipment.

In the Schuckert system, the studs are made of hardened cast-iron, and they are placed between the track rails, embedded in blocks of moulded furnace slag. This slag has been found, by experiment, to be an excellent insulator, and to stand the road traffic in a most satisfactory manner. The complete contact block is shown in

Fig. 165, and it is carried either upon a steel sleeper, which also supports the track rail, or upon the ordinary concrete bed. A connecting cable is run from the stud, in each block, to a distributer switch-box, placed on the adjacent footpath, about thirty blocks being connected to each box. The switches are each worked by means of four small electro-magnets, two being used to put the switch on, and two to pull it off. A single switch is shown in Fig. 166.

Fig. 165.



CONTACT BLOCK AND RAILS. SCHUCKERT SYSTEM.

The magnet coils are shunt wound, and take about ·5 ampère at about 25 volts. A large resistance, in series with the coils, absorbs the remaining 475 volts. As will be seen from the figure, the main contact blocks are made of carbon. The switches are arranged around the interior of a cast-iron box, having room for a man to stand inside, without touching the switches. The boxes are placed in an upright position beneath the footpaths, and are provided with an ordinary manhole cover. In

order to insure a watertight joint, an inner cover is also used, which is shaped something like a diving-bell. This fits into a channel which may contain oil, and, without the use of any packing material, makes a reliable joint, practically impervious to moisture.

Fig. 166.

AUTOMATIC SWITCH. SCHUCKERT SYSTEM.

The operation of the switches is as follows, viz.:—The contact studs are placed close enough together for the skate to touch at least two at the same time. Assuming the switch, which is connected to the stud, immediately under the skate, to be on, then a supply of current will be given to the car. When the skate touches the next stud,

a current from the first stud will pass through two of the coils of the second switch, which will close the main contact, as soon as the preceding switch is off, thus making the second stud alive by direct connection to the main. At the same time, auxiliary contacts on the second switch send a current through the reversing coils of the first switch, and so open its contacts. When the skate leaves the contact, the switch arm would naturally fall by gravity, but the reverse current, sent from the preceding switch, acts as a safeguard, in the event of any liability of the switch to stick. The action of the switches is electrically interlocked in a very ingenious manner.

Short-circuiting Skate.—As an additional security against the failure of the switch mechanism, an independent skate, a few feet in length, is used immediately before and after the main skate. Should any contact stud be left alive, this small skate connects it directly to the rail, thus short-circuiting the system, and opening the circuit-breaker at the section box, or blowing the fuse connecting the stud. This device is not peculiar to the Schuckert system, but has generally been adopted on all surface contact systems. Its presence is an indication that, however certain or reliable the action of the switch mechanism may be, the advocates of the system recognize that an additional precaution is necessary, to make it absolutely certain that no stud is left alive.

But even the short-circuiting device may not prove effectual, as it will not open the circuit-breaker unless the contact stud be connected directly to the feeder, and unless the car is travelling slowly enough to give the mechanism time to act. At a speed of 15 miles per hour, and with a short-circuiting skate, say 3 ft. long, the time

of contact would only be about $\frac{1}{7}$th of a second, which may not be sufficient for the purpose. It may also happen that a considerable leak, between the feeder and the contact studs, is taking place, which may be quite sufficient to give a person, or animal, a nasty shock, and yet not be enough to open the circuit-breaker.

The switch contacts, in the Schuckert system, work very effectively, and without arcing, as the circuit is always made at one contact before it is broken at the

Fig. 167.

SWITCH CONTACTS. SCHUCKERT SYSTEM.

other. The horizontal movement of the switch contacts is the best adapted for the breaking of any arc, which may accidentally arise, and is far superior to those switches which work in a vertical position. An enlarged view of the carbon contact blocks is given in Fig. 167, and the method of holding the blocks in position will be readily seen.

In describing the working of the switch mechanism, it was assumed that a contact was made at the first switch. But, in the event of current going off the line for any

reason, it would not be possible to operate the switches, unless some independent source of current be carried on the car. A small storage battery, just sufficient to operate the switches, is often employed for this purpose, but the Schuckert Co. use a small hand-driven magneto dynamo, fixed under the seat of the car, with a handle which can be worked by the driver, or conductor, at any time that may be necessary. This is a much cleaner and simpler method than using a battery.

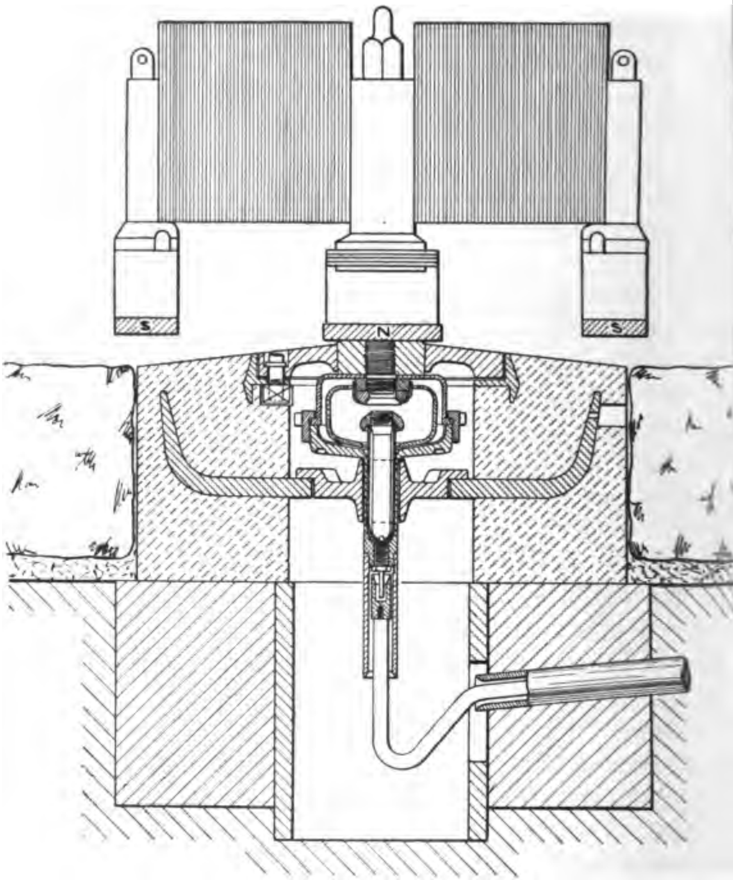
Notwithstanding that it has the inherent defects of any surface contact system, the Schuckert is probably the most satisfactory that has yet been devised. Its electrical details appear rather complicated, but the apparatus is fairly simple, and works well in practice.

We will now consider those surface contact systems, which have the switch mechanism contained within the contact stud itself. The Diatto, Lorain, and Dolter systems all belong to this class, and, in each case, the switch is operated by means of electro-magnets carried upon the skate.

The Diatto System.—The Diatto system is in actual operation, both at Paris and at Tours. The contact studs are set between the rails, in asphalte blocks, and are made of non-magnetic nickel steel. The lower part of the stud consists of a hollow iron box, which acts as a holder for mercury, and is insulated from the cover of the box, which forms the stud proper. The mercury box is connected directly to the main cable, and contains a plunger of steel, with carbon at its upper end. This plunger floats on the mercury, immediately below a second carbon contact, which is fixed to the underside of the insulated box cover. Fig. 168 shows a cross-section of the complete stud with the skates and magnet system.

The skates are three in number, but only the centre one

Fig. 168.



CROSS-SECTION OF STUD, SKATES AND MAGNETS. DIATTO SYSTEM.

is used for making contact with the studs. Five electro-magnets are fixed along the length of the skates, and are

arranged to magnetize them in the manner indicated. The box containing the mercury is provided with two iron "wings," as shown in Fig. 168, and these are imbedded in the asphalte block. Their use is to assist in completing the magnetic circuit.

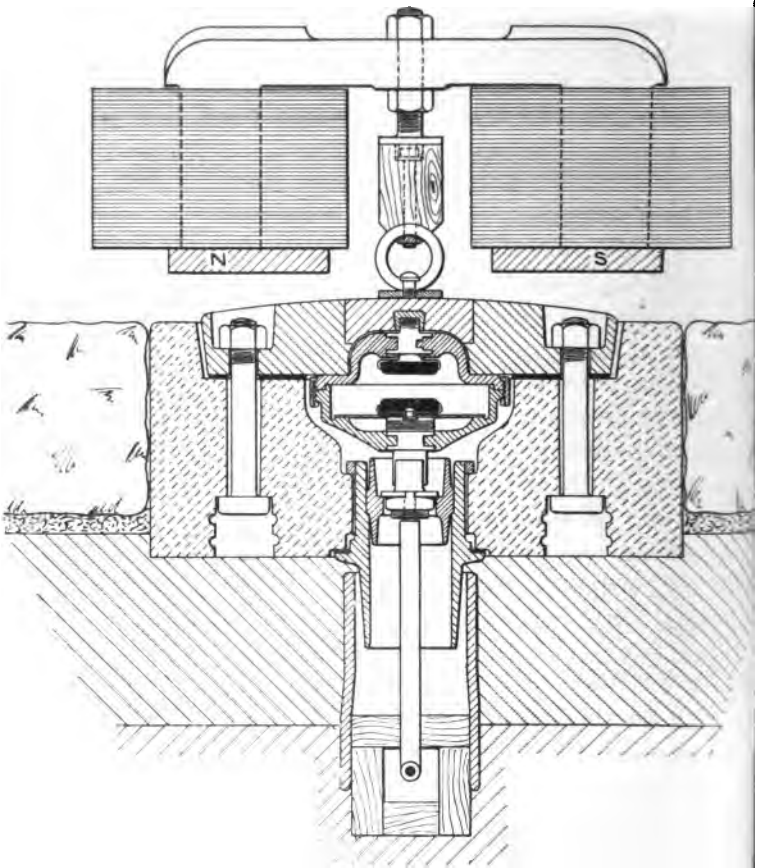
When the skates are over a stud, they attract the steel plunger, and the carbon contacts touch each other, thus making the stud alive. When the skates leave the stud, on account of the passage of the car, the plunger falls back, by gravity, and breaks the circuit. The electro-magnets are operated, partly from the line circuit, and partly from a small battery carried on the car.

The use of the mercury is to take a greater portion of the weight of the plunger, so that only a very small amount of power is necessary to lift it, but a serious disadvantage arises, in practice, from its use. It is found that mercury vapour gradually deposits on the inside of the chamber, resulting in the ultimate connection of the line directly to the stud. A number of accidents have taken place from this cause, and from the improper working of the switches in other respects. The fact, that the circuit is broken in a vertical direction, tends to maintain any arc which may be set up, and, although no arcing is supposed to take place, yet it does in actual practice.

The Lorain System.—The Lorain system, which is now in operation on a line in Wolverhampton, is very similar to the Diatto system, in general principle, but the details of the switches and magnets are different. There are three skates, but only the two outer ones are magnetized. The centre one is made of phosphor bronze, and is suspended, by means of a rubber hose, from a wooden bar between the magnets, thus making contact with the studs. A cross-section of the stud and magnet system is given in Fig. 169.

The studs are made of cast-iron, with nickel steel centres,

Fig. 169.



CROSS-SECTION OF STUD, SKATES AND MAGNETS. LORAIN SYSTEM.

and the lower carbon contact, within the switch box, is carried upon a soft iron strip. This strip is connected to

the supply cable by means of a flat copper ribbon spring, which keeps it normally out of contact with the upper carbon. When the skate passes over a stud, the iron armature and lower carbon contact are lifted up, until a connection is made with the upper contact. There is no mercury to give off any troublesome vapour, but the use of a vertical break switch, with all its disadvantages, is maintained, and, although the line has been working fairly satisfactorily, for some time, in Wolverhampton, there has not been sufficient experience for a correct opinion to be formed as to its ultimate value.*

The Dolter System.—One of the simplest, and probably the best, of those surface contact systems, which have the switches contained within the studs, is that invented by M. Dolter, and now in operation on a short line in Paris. While maintaining the general principle of a magnetic lift for the switch, both the magnetic, and the electrical, details are a considerable improvement on what has been done before.

In the box under the studs is suspended a bell crank lever, with a carbon block at its lower end. The upper arm of the lever is of iron, which is capable of being magnetically attracted by the iron blocks of the stud

ERRATA :

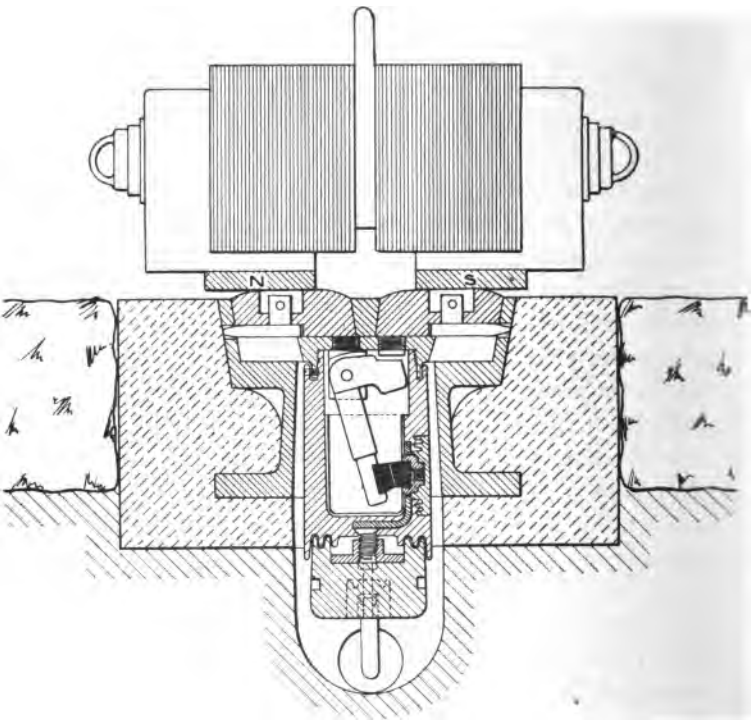
Footnote, page 341.

While these pages were in the press, the Wolverhampton Corporation reversed its former decision, and the Lorain system is now to be used throughout that town.

March 1903.

It will be seen that the stud has two contact surfaces, and that the magnetic circuit is a very short and good one. The switch, in the figure, is shown making contact, thus connecting the line to the stud. The switch lever is loosely pivoted;

Fig. 170.



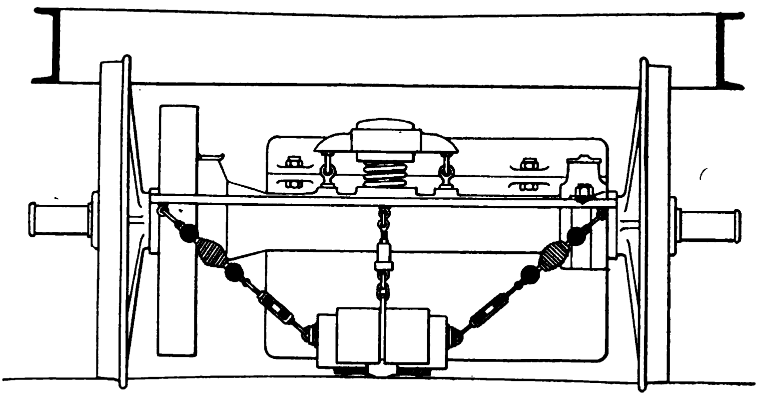
CROSS-SECTION OF STUD, SKATES AND MAGNETS. DOLTER SYSTEM.

and falls entirely by gravity, when the magnetism is removed. It is difficult to see in what way the switch could stick, but, to make sure, a short-circuiting skate is used, as was mentioned earlier.

The skates are two in number, and both are used for making contact with the studs. The electro-magnets on the skate are energized by the line current, and a small, 4-cell, secondary battery is placed in parallel with them, so that their charge is kept up automatically. When the current to the motors is switched off, the cells maintain the magnetism, and keep the switches in contact.

Special attention is given, in the Dolter system, to make the switch chamber absolutely watertight, and, from

Fig. 171.



METHOD OF SUSPENDING SKATES. DOLTER SYSTEM.

the limited experience obtained, this would appear to have been successfully done. A simple device is used, whereby any switch can be readily examined. The whole block can be removed, from its place in the road, by the use of two small hand-keys, the contact with the line being automatically broken.

The method employed to suspend the skates is exceedingly effective. It is shown in Fig. 171, from which it will be seen, that the weight of the magnets and skate

are relied upon, to make the necessary contact with the stud.

Magnetized Skates.—The last three systems, briefly described in the preceding pages, are the only ones in practical operation at the present time. They all belong to the same class, the two latter being, really, developments of the original Diatto system. The use of magnetism, to lift the switches, means a complicated construction of skate, since not only have electro-magnets to be carried, but the skate itself has to be made at least double, in order to present N. and S. poles to each contact stud.

The contact studs, also, have to be made of a non-magnetic material, like nickel steel, with special steel or iron blocks let into it, to form the magnetic poles. There is always the danger of the magnetized skates picking up any loose pieces of iron or steel, which may be lying in the roadway. This may not be of serious moment in some towns, but, in others, and more particularly in the iron manufacturing districts, it will certainly prove troublesome, as has already been found at Wolverhampton, where many short circuits between the studs and the rails, at special work, have taken place from this cause.

Stud Switches *v.* Multiple Switch-boxes.—The principle of employing switches contained in the studs, is, in the Author's opinion, not the correct one, as the switches are more liable to damage, it is more difficult to locate the damage, and the damage is more troublesome to repair. On account of the independent action of each switch, a faulty one may go undetected for a considerable time. The additional complication of carrying a conductor from each contact stud to a multiple switch-box, under the footpath, would appear to be less of an evil than to have

the switches in the roadway, and to be well worth any additional expense.

The Diatto and Dolter systems rely upon gravity alone for opening the switch. While gravity is, perhaps, the most certain of all forces in its action, yet friction can readily counteract it, and a heavy switch-arm is, necessarily, a slow moving one. In this respect, the Schuckert system, with its electro-magnetic pull-off, in addition to gravity, and its light moving parts, is superior.

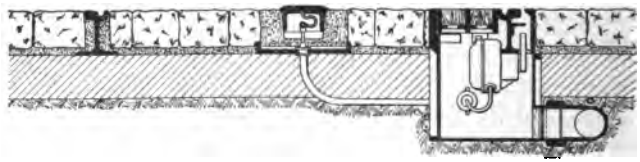
All electro-magnetic switches are liable to be affected by damp, and they all take time to operate. This means, that if the car travel beyond a certain critical speed, the switch may not have proper time to make contact, before the car has passed the stud. This will, of course, depend upon the rapidity of action and lightness of the switch parts. The studs have, therefore, to be set much nearer together, than is theoretically necessary, to make certain that the switches will operate in time. This increases the cost of construction and maintenance.

The Kingsland System.—A form of mechanical operation for the switches has recently been introduced, under the name of the Kingsland system. Its general features are as follows:—

The contact studs are solid fixtures in the road, just as in the Schuckert system, and they contain no switch mechanism of any kind. The switches are placed beneath the roadway, in boxes, immediately underneath one of the track rails, the switch case being bolted to the rail. The switches are not grouped together, but there is an independent switch opposite each stud. A long channel is constructed, parallel to the track rail, forming a conduit, very similar to the side-slot conduit, described in Chap. X., excepting that the conduit is not deeper than the rail

itself, and that the slot of the conduit is outside the rail and separate from the wheel groove. The track rail is of the ordinary girder pattern, and it forms one side of

Fig. 172.



CROSS SECTION OF ROAD. KINGSLAND SYSTEM.

the conduit, as shown in Fig. 172, which is a cross-section of the road, at a switch-box.

Fig. 173.

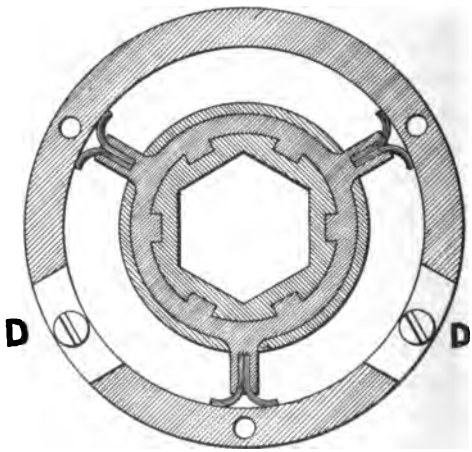


DIAGRAM OF KINGSLAND SWITCH.

The switch-box is carried in a cavity, under the rail, and is connected directly to the stud. The switch is provided with a lever, which projects a little way into the

shallow conduit, so that it may be acted upon by a striker bar, which is fixed to the car. There are two strikers on each car, attached to the forward and rear axle-boxes. The forward striker puts the switch into the "on" position, and the rear striker puts it into the "off" position.

The arrangement of the switch is shown in Fig. 173. It consists of two principal parts, the outer case of insulating material, with two contact plates D, D, and an internal revolving portion, carrying three flexible brushes, set at an angle of 120° with each other. The two contact plates D, D, in the outer ring, are also set at the same angle.

Fig. 174.

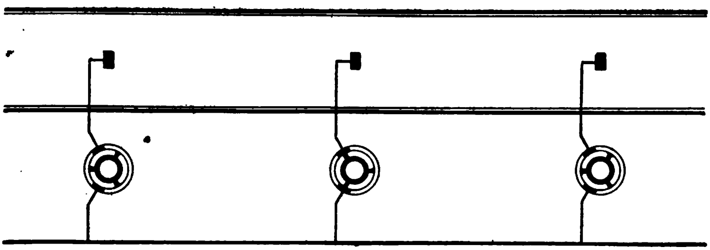


DIAGRAM OF SWITCH CONNECTIONS. KINGSLAND SYSTEM.

The stud is connected to one of the contact plates, and the line to the other.

It will be seen from the figure that, in whichever direction the switch is turned, it will alternately make and break contact, and the whole is arranged, so that the striker bars move the centre-piece one-sixth of a revolution, each time the switch lever is moved. Fig. 174 shows, in diagram, the arrangement of the connections, the centre switch being connected, and the two outer switches disconnected.

In order that the switch lever shall be in a position to be worked by the rear striker, after it has been de-

pressed by the forward striker, it must come back to the vertical position immediately it has been moved. To do this, a double ratchet wheel, with teeth sloping in opposite directions, is employed, in conjunction with a spring. When the lever is depressed, in either direction, it engages with the teeth of one or the other of the ratchets, and turns the switch one-sixth of a revolution. When the striker has passed, the spring brings the lever to the vertical position again, and the rear striker moves the switch through a further distance, and brings it into the off position. In whichever direction the car is moved, that part of the double ratchet comes into use, which is required to turn the switch in the right direction.

The details of the switch are very ingenious, but whether the mechanism will stand repeated blows, from the strikers of cars travelling at a high rate of speed, is yet to be proved.

The skate can be made in a similar manner to the one employed on the Schuckert system, and its action is entirely similar. In order to avoid sparking, within the switches, it is necessary that the distance, between the front and rear strikers on the car, should be greater than the length of the skate, so that the stud shall always be in circuit, before the skate actually touches it, and so that it shall not be cut out of circuit, until the skate has left it.

It is claimed, by the inventor, that the distance between the studs can be made practically twice as great as that required when magnetic switches are used. This is stated to be because there is no time element to consider, the switches being bound to go on and off, just as fast as the car moves, the action being purely a mechanical one.

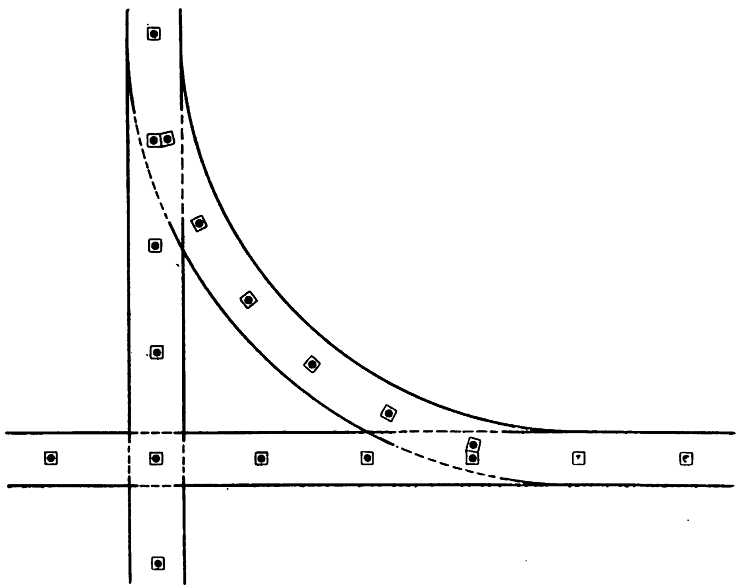
It was mentioned earlier, that the striker was carried on the axle-box. This is because it is necessary that it should be unaffected by any movement of the car body, or the truck. The striker is brought in front of the wheel, at either end of the car, and is supported on a hinged arm, so that it may accommodate itself to curves on the line. It will be noticed, in Fig. 172, that a small bracket is attached to the track rail, immediately over the switch lever. This is for the purpose of preventing the lever from being tampered with, by means of anything passed through the slot. The strikers on the car are curved so as to pass the bracket easily.

It will be seen that the Kingsland system necessitates the use of a slot on the surface of the road, and a shallow conduit beneath it. It has, therefore, all the road surface objections of the ordinary conduit system, while the conduit itself is far more liable to be choked up with dirt, since it is of comparatively small capacity. At each switch-box a connection is made to the drain, and the inventor claims that the whole arrangement is unaffected by damp, dirt, or storm water. But it is more than likely that actual experience, under ordinary working conditions in a public roadway, would soon modify this opinion. Up to the present the system has only been tried upon an experimental private line at Wolverhampton.

Insulated Rail Crossings.—One peculiarity of all surface contact systems is, that, at special work, where one track crosses, or branches from another, the piece of rail, which lies between either of the tracks, has to be insulated. Otherwise the skate under the car, in passing over it, would be extremely likely to touch both it and the stud at the same time, and so cause a short circuit. This will be clear from Fig. 175, where the piece of track, shown in

dotted lines, must be insulated. The skate is ordinarily supposed to keep clear of the paving, and to touch only the studs, which project some half-an-inch above. But, in practice, it is difficult to adjust the skate as closely as this, and, in order to make good contact, it has to be

Fig. 175.



INSULATED RAILS AT JUNCTIONS AND CROSSINGS.

hung so low, that it often rubs along the paving between the studs. On some surface contact lines, sensible grooves have been worn in the paving from this cause.

It is not an easy matter to insulate a track rail, and to give it a good mechanical support, in the shape of tie-bars, or fish-plates, at the same time. To get over this diffi-

culty, dummy insulated studs are sometimes used, one on each side of each rail crossing, so as to lift the skate for an inch or so, above the rail, as it passes over.

Cost of Surface Contact Systems.—Whether surface contact systems have a future or not is very difficult to prophesy. Their only justification is that they get rid of the overhead wires. They are certainly cheaper in construction than the conduit system, averaging from £8,000 to £10,000 per mile of single track, including rails and paving. They necessitate far less disturbance of the surface of the road during construction, as it is not necessary to excavate lower than for the ordinary concrete foundations under the track rails. The weak point, in all such systems, is the use of a switch for each individual contact stud. No engineer, who values his peace of mind, would willingly put down a system which means the use of, probably, 1,000 switches per mile of roadway, the failure of any one of which may have fatal results.

CHAPTER XII.

ACCUMULATORS.

Secondary Battery—Accumulators for Electric Traction—Carried upon the Cars—Position of Cells—Cells under the Seats—Cells on separate Truck—Cells under the Car—Advantages and Disadvantages—In Combination with other Systems—Instances of Combined Systems—Advantages of Combined Systems—Methods of Charging—Fixed Accumulators—Effect of Accumulators on Load Factor—Economical Load—Accumulators as a Stand-by—Comparative cost of Accumulators—Dynamos for use with Accumulators—Charging Pressure—Boosting—Compound Wound Booster—Automatic Switches—Variation of Capacity—Maintenance Contracts—Working Instructions.

Secondary Battery.—The trouble and expense, of constantly renewing the various parts of a primary battery, are very great, and this has prevented its use, except for very light and intermittent work, such as for electric bells, telephones, or telegraphs. When a battery is required to supply electrical energy, at the rate of many horse-power, and for several hours at a time, such as is necessary in a tramway system, then a "secondary" battery must be used.

A secondary battery is one in which the metal plates are brought into an active condition, by passing a current through them from an outside source, generally a dynamo. For example, if two similar lead plates be immersed in dilute sulphuric acid, they will not give any current. But, if a current be passed through them, while in the liquid, the condition of one of the plates will gradually change, a peroxide of lead (PbO_2) forming upon its surface, while the other plate is unaltered. If the charging current then

be stopped, and the two lead plates joined by a conductor, a current will be obtained from them. During the flow of this "secondary" current, the peroxide plate will gradually return to its former condition, and the cell will give no further current, until a charging or primary current has again passed through it. From the fact that no current is obtained, until a current has first been put in, secondary batteries are often called "accumulators." Although electrical *energy* may be stored, or accumulated, during the charging of a battery, yet the popular idea, that the same *current* is given out which is put in, is hardly correct.

The only commercial accumulators at the present time are those made of lead plates. As high as two volts per cell may be obtained when charged, with a capacity varying with the size of the cell, and the rate of the discharge. It is not intended here to enter into a description of the many existing types of cells. They all consist of lead plates, treated in various ways, and immersed in dilute sulphuric acid. The chemical changes during charge and discharge are rather complex, but they may be briefly expressed as—

REACTIONS IN A SECONDARY BATTERY.

+ (Positive.)	Liquid.	- (Negative.)	
$PbSO_4$ (Sulphate of Lead)	2 H_2O (Water)	$PbSO_4$ (Sulphate of Lead)	Before Charge
PbO (Oxide of Lead)	$H_2SO_4 + H_2O$ (Sulphuric Acid + Water)	$PbSO_4$ (Sulphate of Lead)	1st Reaction
PbO_2 (Peroxide of Lead)	2 H_2SO_4 (Sulphuric Acid)	Pb (Lead)	Fully Charged

From this it will be seen that the sulphuric acid (H_2SO_4), originally in the liquid, acts only as a conductor, and does not take any part in the reaction. Also that H_2SO_4 is formed during the process of charging, thus raising the specific gravity of the liquid, and acting as a rough indication of the amount of the charge. During the discharge, the reverse action takes place.

Accumulators for Electric Traction.—The use of accumulators, in connection with electric traction, has always been a subject of great interest. The electrically-propelled vehicle, carrying its own store of energy, has appealed to everybody. It has been the dream of inventors, and the text for many a newspaper article. Indeed, from almost every point of view excepting one, the system may be said to be an ideal one. But long, and in many cases dearly bought, experience has shown that electric traction, by means of accumulators upon the cars, is a financial failure. Makers of storage batteries have been the chief supporters of the system, but, until they have produced a cell, which combines lightness with large capacity, and freedom from rapid deterioration, under the trying conditions of traction work, it is safe to prophesy that self contained accumulator cars will never be a great success. Fortunately it is possible to use accumulators for traction purposes, without carrying them about, and there is thus a large field open to them.

In considering the subject we will do so under the three general heads of—

(1) Accumulators carried upon the cars.

(2) The same as (1), but in combination with the overhead system.

(3) Accumulators fixed in the generating station, or in sub-stations.

1. *Accumulators carried upon the cars.*—Having only one car to propel, each set of cells has to be large enough for the maximum current taken at any time by that car, although the average working current would be probably not more than one-third of the maximum. The required capacity of the cells will depend upon the gradients the car has to run over, and also upon how often it is convenient to charge them. Whatever method is adopted for carrying the cells, they have to be propelled as well as the car itself, and, as they weigh several tons, the total amount of dead weight to be hauled about becomes very considerable.

Position of Cells.—In deciding upon the best position for carrying the cells, the chief points to consider are—(*a*) Ease of removal for charging, and replacement after charging, and (*b*) Liability of causing annoyance to passengers, and damage to the car, from acid spray and fumes. The operation of charging a battery takes a considerable time, and it is therefore not often practicable to keep the car waiting while the charging is done.* Unless the cells can be charged while the car is running, they must be removed at intervals, and a fresh set substituted. As the cost of handling the cells is a very considerable item, and as the cells may be readily damaged in moving them, it will be seen that their position has a great deal to do with the success of the system.

The most usual method of carrying the accumulators, has been to store them under the seats of the car, while the suggestion has been made to place them on a separate truck, either trailing behind the motor car, or running in front. By far the best method, however, would appear to be that of carrying the cells in a special receptacle, under

* This, however, is the method adopted on one of the Paris lines.

the car body and between the axles. This has been adopted in the more recent examples in New York, Chicago, and Paris.

Cells under the Seats.—When the cells are carried under the seats of the car, great care has to be taken to secure good ventilation, to prevent any acid fumes entering the car. The cells are difficult to handle properly, being divided into two sections, one on each side of the car. Special platforms are generally provided at the charging stations, the cars being run alongside, and the accumulators withdrawn for re-charging, while a freshly-charged set is pushed into place. The side panels of the car are hinged to allow of this.

Cells on Separate Trucks.—Placing the cells on a separate truck has the advantage, that they may be charged without lifting them from their position, the truck itself being run into the station, and another one, with fully-charged cells, run out to take its place. A development of this method would be to place the motors also upon the battery truck, and thus to make practically an electric locomotive, the passenger car being simply a trailer. In any case however, to run two cars, or sets of trucks, where only one is necessary, is not good practice, as it not only adds to the amount of dead weight to be moved, but also to the capital cost.

Cells under the Car.—The method of carrying the cells in a special frame or tray below the car, would appear to be the best, and for the following reasons, viz.—(*a*) The ventilation is most easily arranged, without any danger of the fumes entering the car. (*b*) The cells can be readily removed, *en bloc*, when desired. (*c*) The centre of gravity of the car is kept low. There are accumulator lines in New York and Chicago, which have practically identical

arrangements for handling the cells, the method of working being as follows, viz.—

The cars are specially arranged, with the motors suspended on the outside of the car-axles, to leave room for the battery under the middle of the car, between the axles. To provide still further space, the wheel-base is longer than is the general practice. The cells, numbering from sixty to seventy-two, are carried in a tray, suspended by hangers from the top framework of the truck. The tray is of oak, with four channel-irons at the bottom. When the cells require charging, which is usually after about twenty-four miles' run, the car is taken into the shed, and over the charge-pit. By means of an elevator, running on a track at the bottom of the pit, the battery tray is first elevated high enough to disengage itself automatically from the hangers. The tray is then lowered, and run along, on the elevator, to the charging position. Another set of cells, fully charged, is brought into place, by means of a second elevator, and the car is ready for work again. The terminals make contact as the battery tray is lifted to its position. The time required for the complete change is about 1½ minutes, and the cells, with the tray, weigh about 8,000 lbs.

Advantages and Disadvantages.—The advantages, which are gained by the use of the accumulators upon the cars, may be briefly summed up as follows, viz.—

(*a*) No bonding of the track is required.

(*b*) No overhead or underground work is needed.

(*c*) Each car is independent of the power-station, until the cells have to be re-charged.

(*d*) A constant load may be kept on the generating plant, by properly arranging the times of charging.

These advantages are worth a great deal, but the corre-

sponding disadvantages more than outweigh them. They are—

(*a*) The extra power taken to drive the car, owing to the weight of the cells, which often amounts to 25% of the weight of the complete car.

(*b*) The consequent greater wear and tear of the permanent way.

(*c*) The expense of removing the discharged cells, and substituting charged ones, every few hours.

(*d*) The increased capital (and therefore annual) cost.

(*e*) The inefficiency of the cells, as transformers of electrical energy, probably not more than 60% to 75% of the power put into them being available in practice.

(*f*) The rapid deterioration of the cells, owing to the sudden and relatively heavy discharges, and the continual handling.

The use of accumulators upon the cars has been persisted in, only where æsthetic considerations come largely into the question. The existence of combined accumulator and trolley systems, shows that, had the promoters of these tramways a free hand, the accumulators would have been either entirely abandoned, or located in their proper place, viz.—the generating station.

(2) *Accumulators in combination with other systems.*—The opposition which has been raised, by some local authorities, to the use of overhead conductors, has resulted in the development of a combined system, in which accumulators, carried upon the cars, are used within certain areas, and the overhead system outside.

Instances of Combined System.—While such combinations are never desirable, on account of the increased expense of working, and other difficulties, yet their use has been

almost compulsory in some cases, in order to meet local requirements. There have been instances at Berlin, Dresden, Hanover, and Paris, and, while the experience gained shows that accumulators, worked under such conditions, are more satisfactory than when used alone, yet it also shows that overhead conductors throughout are to be preferred.

Advantages of Combined System.—The cells need only be large enough to drive the car, over those parts of the track where there is no overhead conductor, and, consequently, they can be much lighter, than when they have all the work to do. As a result of this, the wear and tear of the permanent way is less, and the inefficiency of the cells is of less relative importance, since a much smaller amount of the total energy, used in driving the car, is passed through them.

Methods of Charging.—When the car is driven by the cells, the trolley arm is tied down, and, when that part of the track is reached where the trolley wire begins, it is an easy matter to place the arm in position upon the wire. The number of cells on each car is generally such that, when charged, their voltage is equal to the normal voltage of the overhead line. In this state they would not take any current from the line, but would assist in supplying the motors, should there be any temporary reduction of pressure on the line, due to overload or other causes. When discharged, however, the pressure of the cells would fall below that of the trolley line, and so a charging current would be taken from the wire, in addition to that for driving the motors. If the overhead section were of considerable length, as compared with the accumulator section, it would be possible to arrange matters, so that all the charging could be done from the overhead wire,

and the trouble and expense of moving the cells would be avoided.

For this method to be successful, not only would special precautions have to be taken, in ventilating the cells and the cars, to avoid any nuisance to passengers from the gases and spray, which would be given off during the charging process, but the pressure of the overhead line would have to be kept constant. This would necessitate an elaborate system of feeders, since any accidental blockage of the traffic may mean a number of cars starting practically together, and thus taking a very heavy current at one place. Even in ordinary working, considerable variations of line pressure are not uncommon, and this would seriously affect the proper charging of the cells. It may happen, therefore, that when the car had returned to the accumulator section of the track, the cells would not be charged sufficiently to enable them to perform their share of the work. The use of accumulators on the Berlin cars has recently been abandoned on this account.

In Hanover, the cells are charged from the trolley wire, and an additional charge is given, when the cars are returned to the car shed. In Paris, the cells are charged at certain stopping-places, the time occupied in the charging varying from eight to ten minutes.

One of the disadvantages of carrying the cells upon the cars, in the manner described, is that a large amount of dead weight has to be hauled about, over the overhead conductor section. If the cells were upon a separate truck, trailing behind the motor car, this could be detached at certain points, the cells charged without any risk of inconvenience to persons on the cars, and the motor car relieved of the extra weight, when taking current from the trolley wire.

(3) *Accumulators fixed in the generating station, or in sub-stations.*—When a number of cars can be run from one battery, fixed either in the generating station, or in a sub-station, a far less jerky load curve is obtained for the cells, than when each set has only its own car to propel. Owing to the improbability of all the cars starting together, the maximum output is much lower in proportion to the average output, and the strains on the cells are much reduced.

Large transformers, in sub-stations, are much more efficient, and, with a given capacity in kilowatts, will allow of a much larger lamp connection, than a number of small house transformers. In a similar way large batteries, in stations or sub-stations, are much more efficient, and, with a given output, will maintain a much larger car service, than if divided amongst a number of cars.

Effect of Accumulators on Load Factor.—Owing to the rapidly fluctuating demand, the plant in a traction station is generally working only at a low average load factor. The running machinery must be capable of meeting the maximum demand, while the average load probably does not exceed one half of the maximum. The advantages of accumulators are most apparent here, and the wonder is that they are not used in more traction schemes.

In the first place, the accumulators would take the peaks of the load, thus relieving the machinery of the sudden jerks caused by the starting of the cars, and, in the second place, the amount of running plant could be reduced to that sufficient for the average load. Fig. 176 illustrates this.

These curves were taken on the Plymouth tramway system, and are self-explanatory. It will be seen that the pressure varies from about 520 to 540 volts, the current taken by the cars from 0 to 200 ampères, and

load, while, with the boilers and piping, it is still more difficult. Steam has practically to be kept up, for the whole of the twenty-four hours, in as many boilers as will be required at the maximum load, and the whole of the steam piping kept connected ready for use. So that at, say, anything under three-quarters of the maximum load, the steam plant is generally working uneconomically, because of the large "stand-by" and radiating losses.

It would therefore pay to run one of the dynamos, if necessary, for the sole purpose of charging accumulators, when the load on the plant as a whole had dropped to an uneconomical point. Or, if a dynamo be running, in order to supply electricity for other purposes, and it can only run under such conditions at a low load factor, then it would pay to use its surplus power for charging cells.

The discharge from the cells can be economically used at any time, when a dynamo would otherwise have to run lightly loaded, as, for example, when the load on the station was more than x dynamos could do, but was considerably under the output of $x+1$ dynamos. Or, when the gain in efficiency, by using the steam plant direct, would be more than counterbalanced by the extra number of men required to work it.

It may therefore be stated, as a general rule, that it will pay to use accumulators in a traction station, if they can be both charged and discharged at a time when the steam plant, or part of the steam plant, would otherwise be working at an uneconomical load.

It is practically impossible, in any station, to arrange that all the plant working is kept at an economical load for any length of time. The demand is constantly varying, and oftentimes in a most unexpected manner. So that, in almost every station, a set of accumulators

would be of service, the cells being used to level the load on the plant. We all want the "load curve" of our steam plant to be a horizontal straight line, and accumulators will help us to obtain this, by filling up the hollows with a charge, and by levelling the peaks with a discharge. The cells should be fully charged at a time when the ordinary tramway service is either suspended, or very light, say between 11 p.m. and 6 a.m.

The use of accumulators will thus enable us not only to reduce the amount of generating plant, but also to keep that plant running at an economical load, for practically the whole of the twenty-four hours, instead of at an uneconomical load for, say, only eighteen hours per day.

Accumulators as a stand-by.—Accumulators are of far more value in any station, when used in this way, than when kept solely for the purpose of acting as a stand-by, in the event of a failure of any of the plant. Of course, when charged, they would always be available for this, up to the limit of their output, but, primarily, their use should be to supplement the plant, by helping it to work at an economical load.

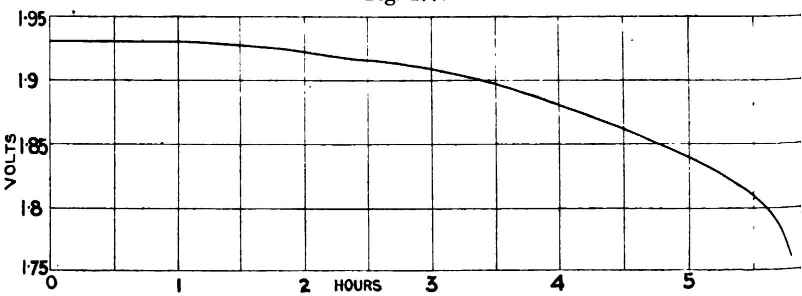
Comparative Cost of Accumulators.—The prime cost of a battery for a given output (for, say, five hours), is, roughly, the same as for steam dynamos and boilers for the same output. The maintenance need not be more than 5% per annum, if the cells be properly treated and looked after, and this is about the same as for the steam plant.

Dynamos for use with Accumulators.—In order that the accumulators may take their share of the load in the manner indicated in Fig. 176 it is necessary that they should be of ample size, with a low internal resistance, and that the dynamos be shunt-wound, with a falling "characteristic" pressure line.

Dynamos for traction work are generally made compound-wound, with a slightly rising characteristic, in order to compensate for the fall of pressure along the feeders. But, owing to the liability of reversals, compound-wound dynamos are not suitable for use with accumulators, and, when cells have to be used with such machines, arrangements should be made for cutting out the series winding.

Charging Pressure.—When connected in parallel with the dynamos for discharging, the number of cells must be

Fig. 177.



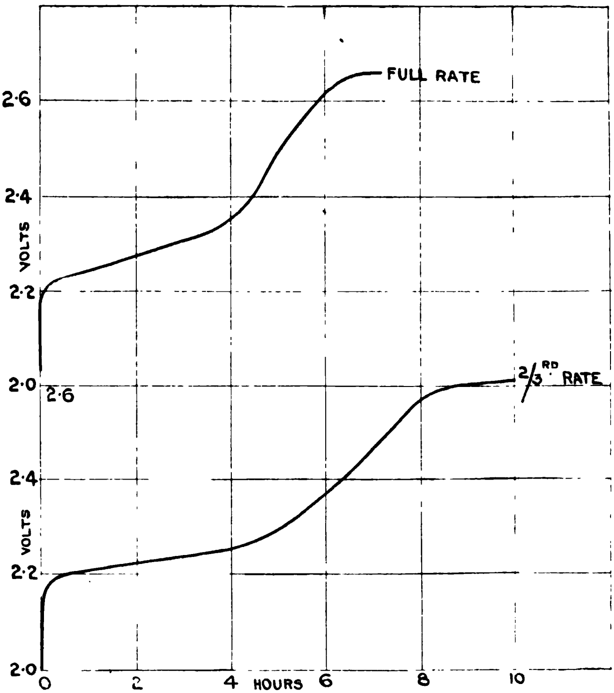
DISCHARGE VOLTAGE OF ACCUMULATOR.

such as to give a pressure equal to the dynamos. But when it is required to charge the cells, the dynamos used for that purpose must be capable of giving a voltage at least 25% higher than the normal. This is because, while the voltage of a cell remains sensibly constant throughout the discharge (see Fig. 177), it gradually rises during the charge, as shown in Fig. 178, owing to the chemical action and the formation of gases.

Boosting.—For many reasons it is impracticable to raise the voltage of the dynamos to such an extent, and it would not be economical to keep a special machine for the purpose, wound for the higher voltage. By far the best

way is to add to the voltage of the bus-bars, by means of a small, separately excited, booster, placed in the cell-charging circuit. The booster could be carried on an extension of the shaft of one of the ordinary generators,

Fig. 178.



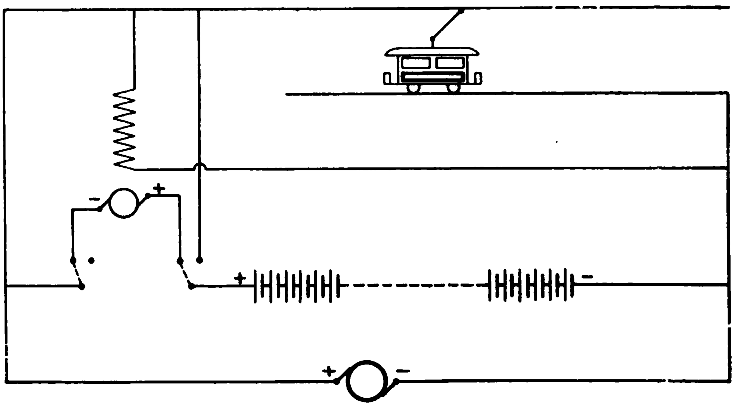
CHARGE VOLTAGE OF ACCUMULATOR.

or, better still, could be independently driven by an electric motor. The rate of charge of the cells could then be regulated, to any extent, simply by varying the excitation of the booster, without in any way altering the pressure of the bus-bars. Fig. 179 shows how the booster would be connected to the circuits.

Compound-wound Booster.—To assist the accumulators to discharge, when the total load exceeds the output of the dynamos, and to charge when the load is less, a compound-wound booster is sometimes used, in the manner indicated in Fig. 180.

The booster, which is shown motor-driven, has two field windings (a shunt and a series) in opposition to one another. When the line circuit is equal to the output of

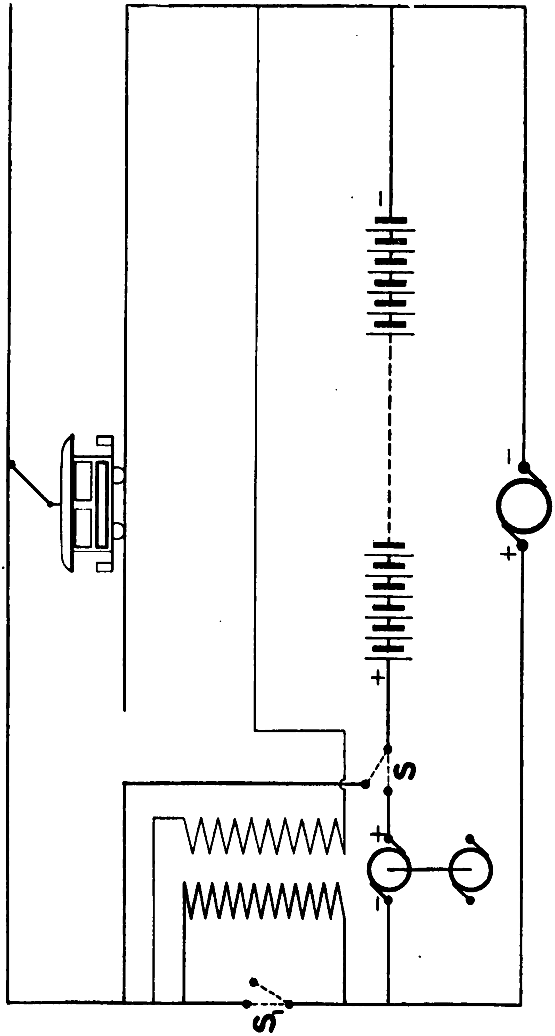
Fig. 179.



CONNECTIONS OF CELL-CHARGING BOOSTER.

the dynamos, the two windings are arranged to neutralize each other, so that the booster will give no pressure. Then the battery will neither charge nor discharge. When the line current is less than the output of the dynamos, the shunt-winding will predominate, and the booster pressure will be in the right direction for charging the cells. When the line current is greater than the output of the dynamos, the series winding will change the polarity of the booster magnets, and it will add a pressure to the battery circuit, thus helping it to discharge. By

Fig. 180.



CONNECTIONS OF COMPOUND-WOUND REVERSIBLE BOOSTER.

means of the switch S, the battery can be connected directly to the line when required, and, by short-circuiting the series windings with the switch S_1, the booster can be used at any time, excited by one winding only, as in Fig. 179.

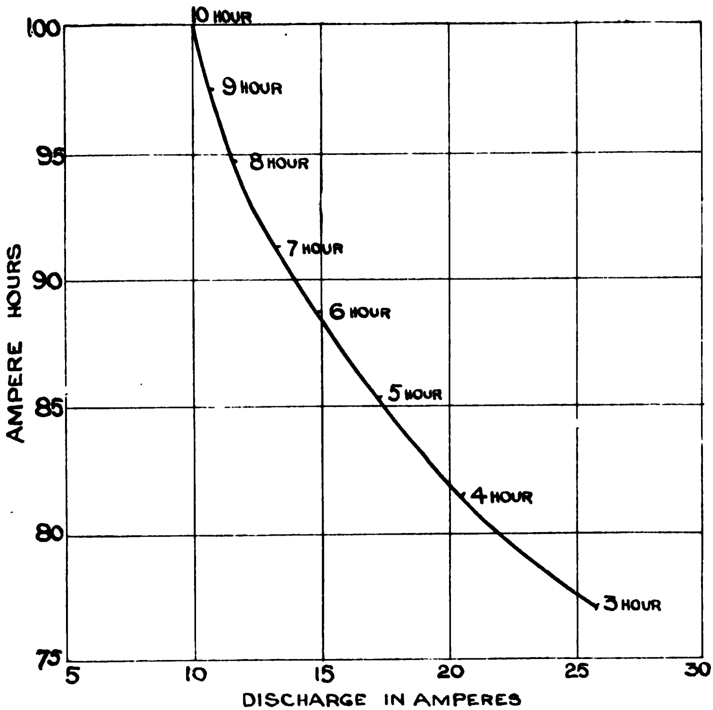
Automatic Switches.—Another method is that adopted by Prof. Mengarini, on the Rome tramways. Instead of varying the pressure at the terminals of the accumulators, by the interposition, in the accumulator circuit, of an adjustable booster, controlled by the line circuit, he varies the number of cells in the accumulator circuit, so that, with a fixed machine voltage, the battery may be charged and discharged, at such rates as to keep the output of the traction plant constant. The switches, on the regulating cells, are automatic in their action, being controlled by solenoids suitably arranged and connected. The battery at Rome consists of 304 Tudor cells, and, out of these, 108 cells are used for regulating purposes, the switches cutting in or out three cells at a time.

At Leeds also, where accumulators are fixed in sub-stations, at the end of long lines, automatic switches are used for the same purpose. There are both charge and discharge regulating switches, the former being connected to a special charging feeder from the generating station, and the latter to the line. As at Rome, the switches control three cells at a time, but the automatic apparatus, consisting as it does of delicate relays and small motors, is much more complicated.

The use of switches, for cutting cells in or out, is to be deprecated at all times, and particularly when they are supposed to be automatic. It will be found practically impossible to prevent unequal charging and discharging of the regulating cells, especially if there be any load on

the mains when charging is going on. Nothing is more liable to cause trouble in a battery, than to have the cells unequally charged. Even at a little sacrifice of efficiency, the battery should, as far as possible, be charged

Fig. 181.



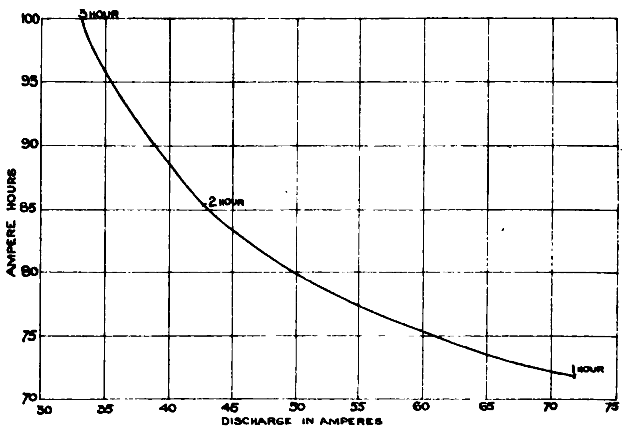
CAPACITY CURVE FOR LOW DISCHARGE RATES.

and discharged as a whole, in order that every cell may be equally treated. This is not possible where regulating switches are used. Unequal use of the cells leads to unequal capacities, with the liability to reversals and all its subsequent troubles.

Variation of Capacity.—It has already been stated that the capacity of a cell varies with its rate of discharge, and, by the courtesy of the Tudor Accumulator Company, Ltd., the Author is enabled to give, in Figs. 181 and 182, curves which show the relation between the discharge rate and the capacity of a cell, when working at either high or low rates.

Maintenance Contracts.—The life of a battery largely

Fig. 182.



CAPACITY CURVE FOR HIGH DISCHARGE RATES.

depends upon its treatment, and nothing will deteriorate more rapidly with inattention. The working instructions issued by the various accumulator makers, to be observed with their cells, should be most carefully followed, as they are the outcome of long experience. Under proper conditions, manufacturers are prepared to maintain a battery up to 100% of its full capacity, for many years, at an annual charge of about 5% of the prime cost, and such maintenance contracts are very advisable, when the

period covered is long enough. Ten years should be a minimum.

Working Instructions.—Below are given the working instructions issued by the Tudor Accumulator Company, Ltd., as they are applicable to most types of batteries.

Battery No. . . . . . . Composed of . . . . Cells Type . . . . . .
Capacity : . . . . . ampère-hours.
Rate of Discharge : ampères for . . . . hours.
Minimum E.M.F. of whole Battery : . . . . volts.
Maximum Rate of Discharge : . . . . ampères.
Rate of Charge . . . . . . ampères.

Discharge.—The rate of discharge should not exceed the maximum given above. The discharge must always be stopped as soon as the E.M.F., measured while the current is still passing, has fallen to 1·8 volts per cell.

Charge.—The rate of charge, given above, should not be exceeded in general working. *Under exceptional circumstances* it may be increased by 25%.

The battery must be *charged fully each time*, until the positive and negative plates gas freely, and large bubbles appear on the surface of the liquid, which should become quite clear.

The voltage at the end of the charge varies between 2.55 and 2.70 volts, according to the rate of charge.

Overcharge.—In general, no injury is done to the cells by slightly overcharging them, *i.e.* by continuing the charge for a short time after the cells begin to gas freely.

In the following cases *an overcharge is required*—

1. Under ordinary working conditions, *once every week for one hour.*
2. When on several preceding occasions the battery has not been fully charged.
3. After the battery has been left idle for some time in a more or less discharged state.
4. When the battery is to remain idle for some time.
5. When for any reason the battery has been discharged beyond the limit given above.

Supervision.—When the battery is nearly charged, the attendant must examine it to make sure that all the cells begin to gas simul-

taneously and equally. The attendant should also take, from time to time, the voltage of each cell at the end of the charge, whilst the current is still passing, and the specific gravity of each cell before it is discharged.

If any cell does not begin to gas with the remainder, or does not gas freely, or if the voltage or specific gravity of any cell is below the average, it is a sign that there is an internal circuit caused by the presence of some conducting matter lodged between the plates. The cell must be at once carefully examined, the internal contact must be removed by passing a strip of wood or glass between the plates, and the charging of this defective cell must be continued until it gives off gas in the ordinary way.

Electrolyte.—The level of the liquid in the cells should be at least half-an-inch above the plates.

The specific gravity of the Electrolyte, when the battery is fully charged, should be 1·200.

To keep up the level of the liquid only water is required; occasionally, if the specific gravity of all the cells, when thoroughly charged, has fallen below the normal, dilute acid (sp. gr. not above 1·200) may be added. No acid must be added to a defective cell; its specific gravity will rise as soon as the cell is restored to its proper condition.

All water must be distilled.—The acid must be Brimstone Acid, free from impurities; a sample of each fresh supply should be submitted for analysis.

CHAPTER XIII.

COMBINED LIGHTING AND TRACTION STATIONS.

Influence of Load Factor on Cost—Combining the Lighting and Traction Loads—Systems of Combination—Separate Plant for both Services—Same Plant for both Services—Accumulators—Comparative Costs—Methods of utilizing Lighting Plants—Direct Current Stations generating at between 400 and 550 volts—Combined Lighting and Traction Dynamos—Direct Current Stations generating under 400 or over 600 volts—Alternating Current Stations—Combined Alternator and Dynamo—Sub-stations—Modern Stations—Division of Management.

Influence of Load Factor on Cost.—From the time when Corporations and Companies commenced the supply of electrical energy for lighting purposes, up to the present, it has been continually stated and proved, that the one thing operating against its cheaper production was the smallness of the load factor. Many suggestions have been made, as to the means whereby the great drawback of cost could be overcome, but none have found such favour, as the one of providing a load for the plant, during the hours of daylight, or, in other words, to secure a constant or nearly constant load. In every business, large output, with the minimum of plant, means cheap supply, and, in the case of electricity supply, large and uniform demand undoubtedly is the one thing needed to reduce its cost.

All this has long been admitted, and the difficulty has hitherto been, not in recognizing the evil, or in knowing

what would be a good remedy, but in providing the remedy itself.

Combining the Lighting and Traction Loads.—The introduction of electric traction into any town possessing an electricity undertaking, at once opens up a large field for the supply of current during the daytime, and every endeavour should therefore be made, by the owners of the lighting station, to sell power to the tramways. The addition of a lighting load, to the ordinary traction station, may not be of much benefit to the latter, but the combination of a tramway and lighting load will be of great service to the lighting station.

The advantages of the combination will particularly be felt, when both the lighting works and the tramways are owned by the Corporation. Municipal lighting works are now very numerous, and many Corporations own, if they do not work, the tramways in their town, while, in the near future, it may be safely prophesied that those Corporations, who willingly lease their lines, will be in a minority. In many instances at present the lessee provides the motive power, generally horses, to deal with the traffic on the lines constructed by the lessors. Therefore, when the time for a revision comes, and Corporations begin to work their lines themselves, they will probably find it necessary to provide a complete equipment of new rolling-stock and motive power.

That electricity will be adopted is practically certain. But the important question to decide, in connection with the generating plant, will be, "Shall the plant be separate and distinct, or shall it be combined with the electric lighting plant ?"

In many cases the plant for electric lighting will be on a system unsuited for direct application to tramway pur-

poses; and the tendency may be to say, that as the purposes are distinct, then the plants should be separate and distinct as well. But this would be unwise, and opposed to the best interests of both concerns.

Whether two separate systems be used in one building, or whether the plants be identical for both purposes, the combination has already been carried out to a practical issue in America, Europe, and elsewhere. The examples of Blackpool, Bradford, Bolton, Dover, Halifax, Liverpool, and Plymouth in this country, without mentioning more than 30 other instances, show that the practicability and importance of the combination are being fully recognized.

There can be no doubt as to the advisability of the combination, and, if properly carried out, it would result in cheapened supply for both purposes. Such a combined plant, worked economically, ought to produce current at (including capital charges) from 1*d.* to 2*d.* per unit, according to the demand. This is simply due to the combined load factor being a very good one. Were the load factor of a purely lighting station equally good, the cost of production could be equally low.

Systems of Combination.—The question, as to the system on which the combination should be made, is a most important one, which we will now briefly consider.

We may have either a distinct and separate tramway plant, within the same building as the lighting plant, and under the same management and control; or we may utilize the existing lighting machinery by various methods.

Separate Plant for both Services.—If we adopt the former, we shall require separate engines and generators, and also additional boilers, which, however, may be worked in conjunction with the existing boilers and steam-pipes. In other words, we shall require nearly as much plant as

though the tramways were being worked from a distinct station. The only advantages will be that the existing buildings (enlarged), and the existing staff and management will be available.

That this must be so will be clear, when we remember that the tramway load will not conveniently shut down, as darkness comes on, but that, for a few hours each day, chiefly during the winter months, the whole of the lighting plant will be required for lighting purposes, and, during this time, the tramcars will have to be driven as well. The effect of this will be to give an excellent day load (after 6 a.m.), but it will also increase the "peak" by an equal amount. Fig. 183 shows the output from the Plymouth Corporation Electricity Works, for March 21st, 1903, with a combined lighting and traction load.

This is a great improvement on the ordinary load factor of a lighting station, but cannot we go still further?

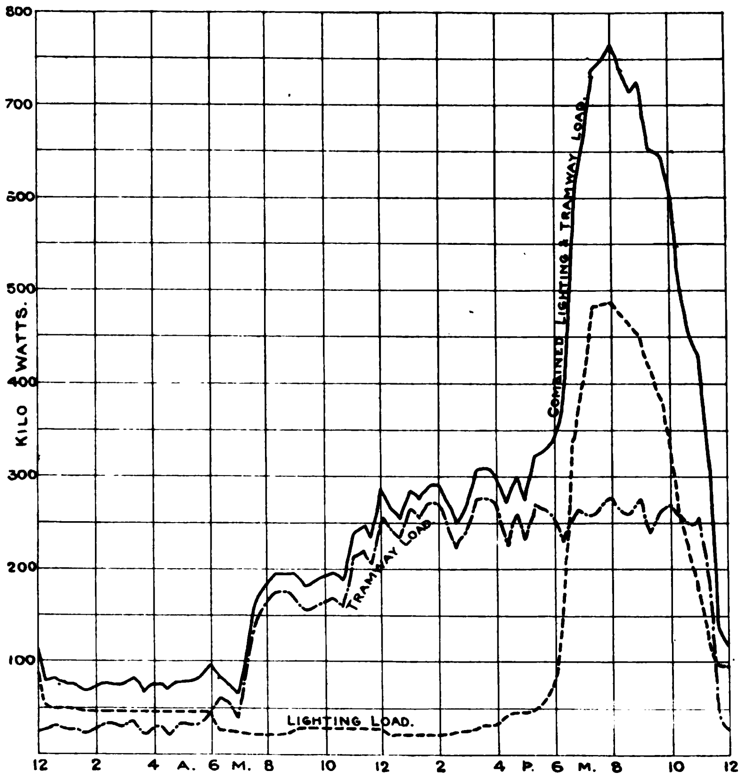
Same Plant for both Services.—If we utilize the existing machinery of the station for driving the cars, we must, in the first place, supply current suitable for tramway purposes, and, in the second place, provide power for running the cars during the time of the heavy lighting load.

If the ordinary station supply be not suitable for direct use, we may obtain anything we want by means of rotating transformers, *i.e.* by coupling a direct current generator to a direct current motor, in the case of a direct current supply, or to an alternating current motor in the case of an alternating supply.

Accumulators.—The power required for driving the cars, during the period of heavy lighting load, may be obtained from accumulators. These should be of sufficient capacity to drive the cars for, say, five hours. The actual number of hours they would be required would vary with the time

of the year. In the depth of winter it is not likely to be more than that, while, in the summer months, it would be very much smaller. These accumulators would be charged

Fig. 183.

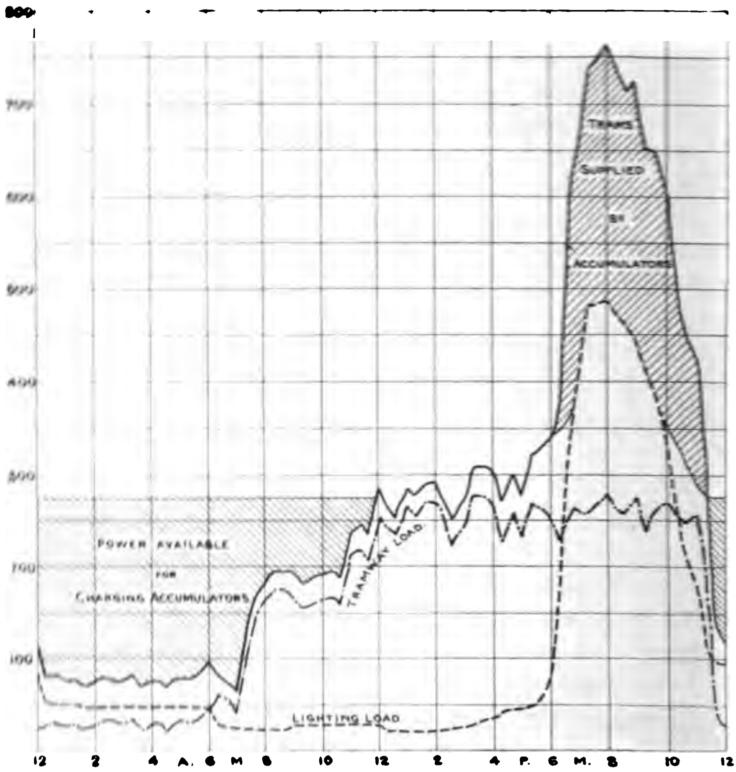


OUTPUT CURVES FOR COMBINED LIGHTING AND TRACTION STATION.

directly from the station machinery, if suitable, or from the same motor-generators which supply the cars. An ordinary winter day's working would be somewhat as follows, viz.—

11.30 p.m. to 6.30 a.m. (seven hours) car traffic stopped, or very light. Accumulators being charged at full rate. Small lighting load.

Fig. 184.



OUTPUT CURVES FOR COMBINED STATION, WITH ACCUMULATORS.

6.30 a.m. to 5 p.m. (ten and a half hours) cars running. Plant, in parallel with accumulators, supplying current for cars. Accumulators helping to furnish such sudden heavy

demands as may arise, and also being partially charged when cars were only taking small current. They would thus remain practically fully charged during this period. Small lighting load.

5 p.m. to 10 p.m. (five hours) cars running. Plant supplying current for lighting. Accumulators supplying entire current for cars. Heavy lighting load.

(As explained above, the actual demand upon the accumulators would depend upon the time of the year, and upon the requirements of the lighting load.)

10 p.m. to 11.30 p.m. (one and a half hour) cars running, but gradually ceasing. Lighting load going off. Plant again in parallel with accumulators. Charging commenced and gradually increasing as lighting and tramway load diminished.

Fig. 184 shows the effect of this method of working, and it should be compared with Fig. 183.

Not only is the load factor a splendid one, but the maximum output of the station machinery, and boilers, is reduced to the maximum demand of *either* the lighting or the tramway load, whichever is the greater, and not to the sum of them. The actual shape of the curves, in Figs. 183 and 184, and the effect of the tramway load upon the system, will of course depend entirely upon local conditions, and will probably vary in each case.

The use of accumulators in the manner described, would have the great incidental advantages of rendering the car service independent of a temporary breakdown of the plant, and of acting as a stand-by for the excitation in alternating current stations. Other points in connection with them are mentioned in Chapter XII.

Comparative Costs.—So far as prime cost is concerned, there is perhaps little to chose between this arrangement

and the former. If motor-generators were used, they would cost nearly as much as their corresponding power in direct-acting steam plant, while the accumulators could be purchased for the money otherwise expended in spare steam plant, boilers, pumps, pipes, and extended station buildings. But, in the annual running expenses, there would be great economy, particularly with respect to the boilers and steam piping. If a distinct plant were used for the tramways, steam would have to be kept up all day in sufficient boilers for the full tramway and lighting loads, as all the power would be required when darkness came on. This would mean a larger chimney, and also more stokers, while the fuel and water consumption would be increased.

The question of a good day load, and consequently cheapened production, is of such vital importance to the electrical industry, that it will repay all the attention which can be given to it. That a combined station is the right thing there can be no doubt.

Methods of utilizing Lighting Plants.—In order to utilize to the utmost the advantages of the combined loads, it is necessary that the existing station machinery should be used as far as possible, and we will now consider, somewhat in detail, the various methods of utilizing the lighting plant for the tramway service.

Assuming that the tramways are to be supplied by any system, other than by accumulators upon the cars, then the pressure required will be in the neighbourhood of 500 volts. The number of stations in this country, generating at between 400 and 550 volts, is not great, and, although they will probably become more numerous in the future, yet, to the large majority, *direct* use of the existing machinery is, for the present, out of the question.

We will consider the various types of present day lighting stations under the following heads, viz.—

(1) Direct current stations, generating at between 400 and 550 volts.

(2) Direct current stations, generating at under 400 or over 550 volts.

(3) Alternating current stations, generating at any pressure, but generally from 2,000 to 2,500 volts.

1. *Direct current stations, generating at between* 400 *and* 550 *volts.*—These will undoubtedly be multiple wire stations, on probably the three-wire system. The voltages of the machines would enable them to be used directly for tramway work, but, to use them at the same time for lighting work, would permanently earth one side of the lighting system, owing to the rail return of the trams. This must not be done, in this country, without the consent of the Board of Trade, and, if their permission be obtained to use an earth connection at all on the lighting mains, it would, without doubt, be for earthing the middle conductor and not either of the outers. It is thus evident that the tramway service cannot be supplied directly from machines, which are supplying a lighting system at the same time. But it may be supplied indirectly, through the medium of motor-generators, used simply for the purpose of keeping the traction and lighting mains separate.

Motor-generators, however, are not required, if the dynamos for lighting and traction be kept distinct. They may be of exactly the same type, be used for either service at will, and even be driven by the same engine at the same time, if desired, but they must be entirely disconnected from one set of mains, before being used on the other. The use of separate engines has the advantage, that the fluctuations of the tramway load do not affect the lighting; on

the other hand, it has the disadvantage, that at least one additional engine must be kept going, probably with only a poor load factor. This latter may be obviated by the proper use of accumulators for each system, but the application of accumulators, to the traction service, would also enable the same engine to be used for the two plants. This may be very desirable in small stations, or where there is only a small lighting load throughout the day.

Combined Lighting and Traction Dynamos.—An arrangement of plant met with, in some lighting stations, is that of having the engine in the centre, and a dynamo on either side, so that both are driven at the same time. Such a plant, probably fly-wheeled, could well be used for the combined services, one dynamo for lighting and the other for traction, unless trouble with the engine-shafts was experienced. But a still better arrangement would be to place the engine outside, and to have a clutch-coupling between it and the two dynamos, as in Fig. 185.

The proper relation, between the power of the engine and the outputs of the two dynamos, would of course have to be determined in each case, and would depend, principally, upon the size of the lighting day load. Such a plant could be used in the following combinations, assuming the voltage of both dynamos to be identical, viz.—

(*a*) Engine driving both, one for lighting and the other for traction.

(*b*) Engine driving both, in parallel for lighting.

(*c*) Engine driving both, in parallel for traction.

(*d*) Engine uncoupled and at rest. Dynamos running as motor-generator for traction, driven either from another lighting dynamo, or from the lighting accumulators.

(*e*) Engine uncoupled and at rest. Dynamos running

as motor-generator for lighting, driven from the traction accumulators.

As has been shown, in Chap. XII., the accumulators would, if properly arranged, obviate all difficulties due to sudden variations of load, particularly if the plant be properly fly-wheeled.

If accumulators were used, on both traction and lighting mains, at the same time, they would, of course, have to be kept as two distinct and separate batteries. If only one battery were in use, it could not be connected to the lighting mains until disconnected from the traction mains, and *vice versâ*, because of the earthing of one side.

2. *Direct current stations, generating at under* 400 *or over* 550 *volts.*—These may be considered together, as in neither case would the voltage of the machines be suitable, for direct tramway work. A pressure under 400 volts would be too low for economical working, and over 550 volts on the line is not at present allowed, by the Board of Trade. Certainly two 250-volt machines could be used in series, but it is not a plan to be recommended, owing to the switching and other complications which would ensue.

Motor-generators can here be used with advantage, in conjunction with accumulators. Current may be taken from the station omnibus-bars if desired, or a separate dynamo may be used to drive the motor-generators. Or a set may be arranged as in Fig. 185, the one machine being of a voltage to correspond with the existing station plant, and the other suitable for traction purposes. The same combinations as before mentioned could be obtained, except that, in (*b*) and (*c*) only one of the machines would be giving current, instead of both, although both would be running.

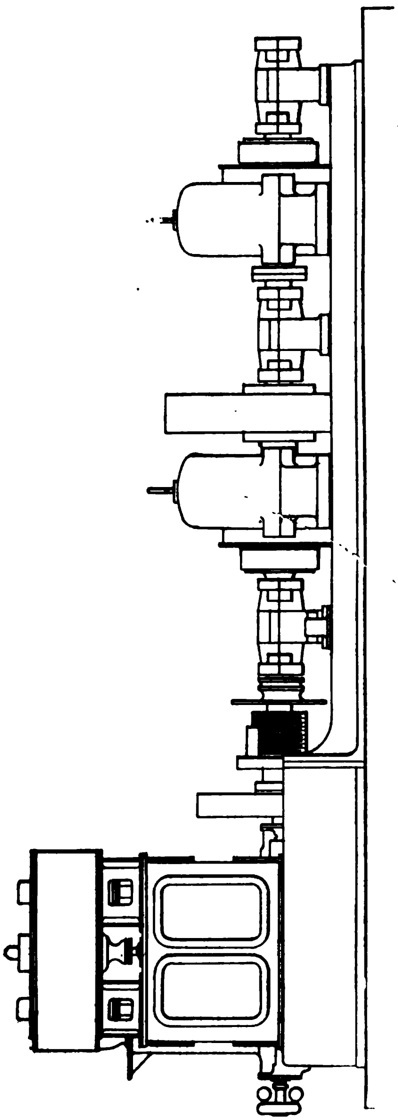


Fig. 185

ARRANGEMENT OF TWO DYNAMOS FOR LIGHTING AND TRACTION.

An interesting method[1] for use in towns served by the "Oxford" system has been suggested by Mr. W. L. Spence.

It involves the use of motor-generators, but the bulk of them would act only as reducers. Thus, for any given demand, for either lighting or traction purposes, the motor-generator would only be one-half that size, with the effect of raising the efficiency of the system.

Fig. 186 shows the proposed arrangement.

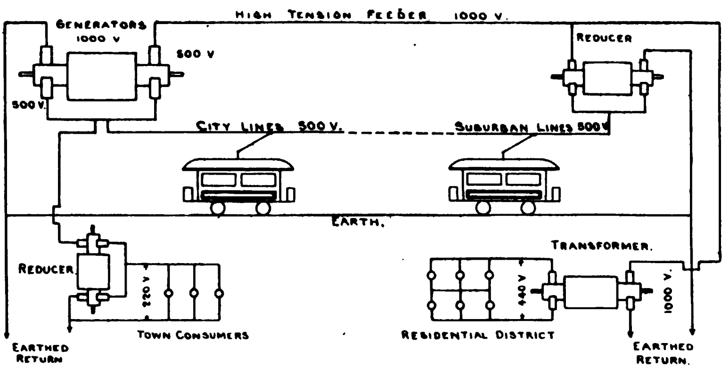
In the power-house all the generators would have armatures with two wind-

[1] See *Lightning,* Dec. 17th, 1896.

ings and two commutators, each for 500 volts. These would be connected in series, enabling two positive omnibus-bars to be used, and giving differences of potential of 500 and 1,000 volts above the negative bus-bar, which would be earthed. The generators would work in parallel, in the usual way.

For feeding the tramways in the immediate vicinity of the station, current would be taken direct from the 500-volt bus-bar, and, for this service, no transformers would be

Fig. 186.



COMBINED LIGHTING AND TRACTION ON THE "OXFORD" SYSTEM.

necessary. For the supply to suburban lines, the current would be obtained from the 1,000-volt bus-bar, and taken to suitable sub-stations, where it would be reduced to 500 volts, for the line. The reducers would each consist of a single armature, carrying two windings and two commutators, having a ratio of about 1 to 1, and connected in series.

The lighting demand would be dealt with in a similar way. All distribution, in the neighbourhood of the station,

would be on a 2-wire system at about 220 to 250 volts, and, for this service, the 500-volt current would be reduced, as already described for the suburban tramway lines. The feeders to the reducing transformers would be 2-wire, and the distance, to which they would reach, would correspond to a 500-volt pressure.

Beyond this radius, the supply would be on the 3-wire system with lamps at from 220 to 250 volts, and the current would be entirely transformed, so that the circuits may be electrically distinct from the other systems, thus permitting the earthing of the middle wire.

Batteries may be used for either service, preferably in sub-stations, so as to improve the load factor on the feeders, as well as on the station plant.

3. *Alternating current stations.*—At the present time, there are very few multiphase alternating current stations in existence, in this country, for lighting purposes, and no single phase self-starting alternating current motors, suitable for use on tramcars. Owing to this, but chiefly to the fact that most alternating current stations generate at high pressures, it is necessary to use transforming apparatus, where it is desired to utilize existing plant. The transformers must do two things: they must lower the voltage from (usually) 2,000 to 550 volts, and they must also change the alternating into continuous current.

There are two ways of accomplishing this :—(1) by means of statical transformers, in conjunction with rotary transformers; or (2) by means of alternating current motor-generators.* In both cases accumulators should be used.

Combined Alternator and Dynamo.—A most useful combination could be arranged, similar to that described in the

* See Chapter IV.

first section, and shown in Fig. 185. Instead of both machines being direct current dynamos, one would be an alternator and the other a dynamo. Fig. 187 shows a side elevation, and Fig. 188 a photograph, of such a set, designed by the Author for use in the Plymouth Corporation Electricity Works, for combined lighting and traction service. The following combinations can be obtained, viz.—

(*a*) Engine driving both, the alternator for lighting, and the dynamo for traction.

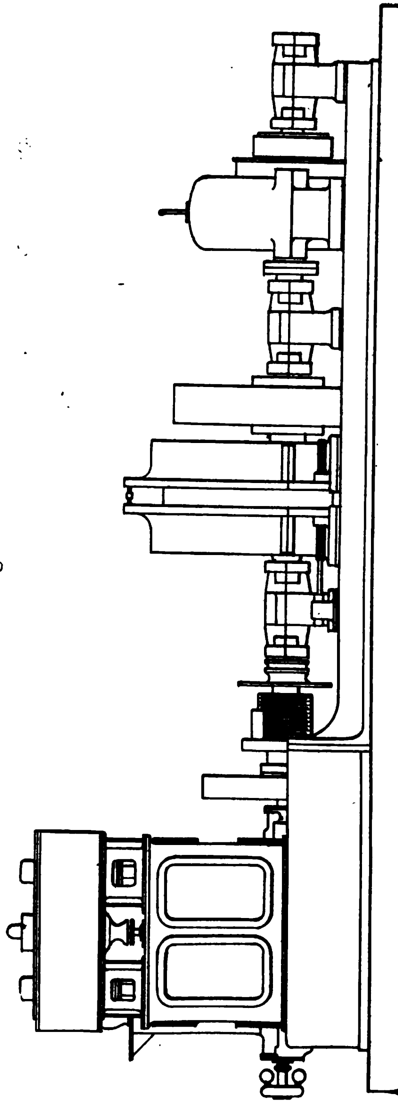
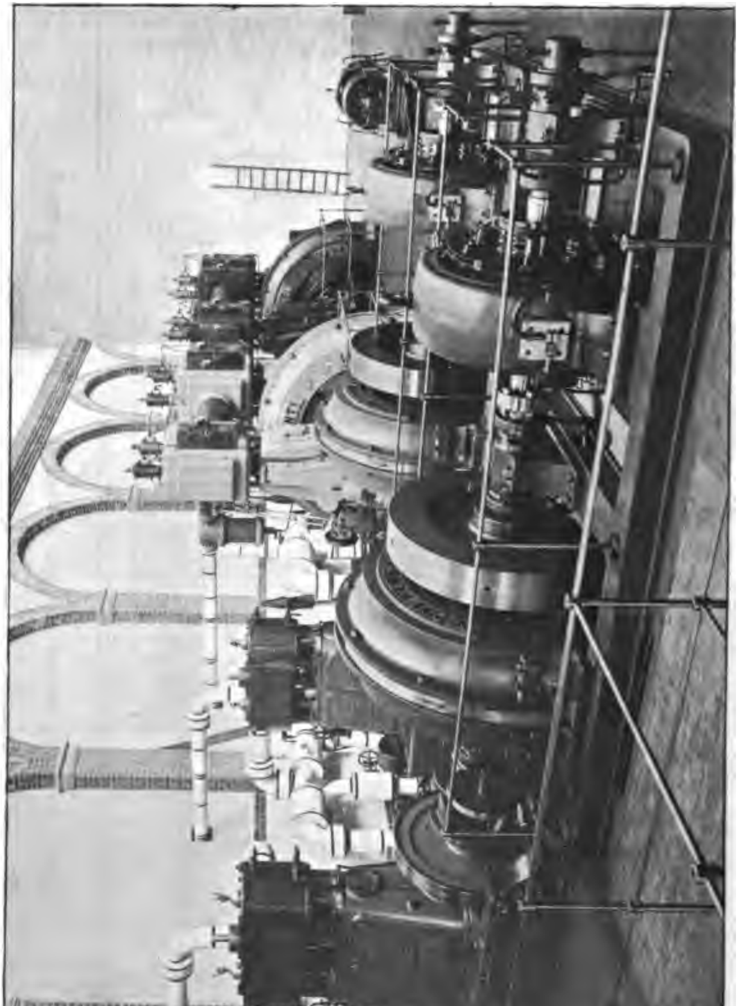


Fig. 187.

ARRANGEMENT OF ALTERNATOR AND DYNAMO FOR LIGHTING AND TRACTION.

Fig. 188.



COMBINED LIGHTING AND TRACTION MACHINES. PLYMOUTH.

(*b*) Engine driving the alternator for lighting, the dynamo running light.

(*c*) Engine driving the dynamo for traction, the alternator running light.

(*d*) Engine uncoupled and at rest. Machines running as motor-alternator for lighting, driven from the traction accumulators or from another traction dynamo.

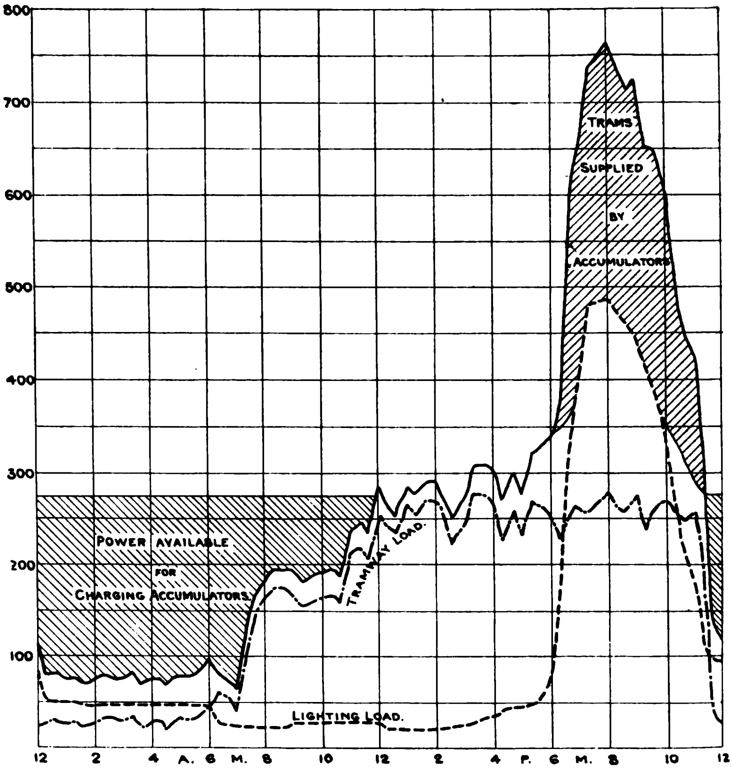
(*e*) Engine uncoupled and at rest. Machines running as motor generator for traction, driven from the lighting omnibus-bars, or from a separate alternator.

Sub-stations.—In all the foregoing examples it has been assumed, that the tramways are being supplied direct from the electricity works. But, when the tramway route lies a long way from the station, it may be more economical to supply from a sub-station, particularly when the station-pressure is considerably above that required by the trams. In these cases, transforming apparatus of some sort becomes necessary, and it will be better to use the high pressure for transmission to sub-stations, and there to transform it, than to transmit it at a low pressure.

The traction accumulators should be fixed as close to the tramway feeding-points as possible, and, in most cases, it would be convenient to place them in the same sub-stations as the transforming apparatus. As explained before, the accumulators are used to take up the inequalities in the tramway load, and to furnish a supply for the cars, during the period of heavy lighting load, thus relieving the station machinery. Under these circumstances the lighting mains could be used for supplying the sub-stations, as the load could be kept practically constant,

11.30 p.m. to 6.30 a.m. (seven hours) car traffic stopped, or very light. Accumulators being charged at full rate. Small lighting load.

Fig. 184.



OUTPUT CURVES FOR COMBINED STATION, WITH ACCUMULATORS.

6.30 a.m. to 5 p.m. (ten and a half hours) cars running. Plant, in parallel with accumulators, supplying current for cars. Accumulators helping to furnish such sudden heavy

demands as may arise, and also being partially charged when cars were only taking small current. They would thus remain practically fully charged during this period. Small lighting load.

5 p.m. to 10 p.m. (five hours) cars running. Plant supplying current for lighting. Accumulators supplying entire current for cars. Heavy lighting load.

(As explained above, the actual demand upon the accumulators would depend upon the time of the year, and upon the requirements of the lighting load.)

10 p.m. to 11.30 p.m. (one and a half hour) cars running, but gradually ceasing. Lighting load going off. Plant again in parallel with accumulators. Charging commenced and gradually increasing as lighting and tramway load diminished.

Fig. 184 shows the effect of this method of working, and it should be compared with Fig. 183.

Not only is the load factor a splendid one, but the maximum output of the station machinery, and boilers, is reduced to the maximum demand of *either* the lighting or the tramway load, whichever is the greater, and not to the sum of them. The actual shape of the curves, in Figs. 183 and 184, and the effect of the tramway load upon the system, will of course depend entirely upon local conditions, and will probably vary in each case.

The use of accumulators in the manner described, would have the great incidental advantages of rendering the car service independent of a temporary breakdown of the plant, and of acting as a stand-by for the excitation in alternating current stations. Other points in connection with them are mentioned in Chapter XII.

Comparative Costs.—So far as prime cost is concerned, there is perhaps little to chose between this arrangement

When both the Electricity supply and the Tramways are the property of the Corporation, it may sometimes be advisable to combine the two undertakings under the management of one committee, with a separate sub-committee to deal with the details of each department.

CHAPTER XIV.

ELECTRIC RAILWAYS.

Examples of Electric Railways—Present Systems of Working—Difference between Local and Main Line Traffic—The Third Rail—Locomotives *v.* Motor Cars—Lighting Car Lamps in Tunnels—Alternating Current Motors—Synchronous Motors—Induction Motors—Speed of Induction Motors—Fall of Pressure on Track Rails with Alternating Current—Cascade connection of A. C. Motors—Advantages of High Line Pressures—D. C. *v.* A. C. Motors—Advantages of Simple System—Single Phase A. C. Motor-Generator System—Single Phase A. C. Series Motor System—Direct Current Series System—Future of Electric Railways.

Examples of Electric Railways.—Immediately electric traction, on tramways, was proved to be both an engineering and a financial success, attention was directed to the much greater problem of electric railways.

At first sight, there may not appear to be much difference between an electric tramway and an electric railway, save in the matter of size and power, and that the former runs through the public streets. Excepting that an insulated third rail has been used, to convey the current to the motors, instead of an overhead conductor, or a conduit, the general principles of tramway work have not been widely departed from, until quite recently.

The only examples of electric railways in operation, at the present time, in this country, are—the Liverpool Overhead Railway, with 13 miles of single track; the City and South London Railway, also with 13 miles of single track;

the City and Waterloo Railway, having 3 miles of single track; and the Central London Railway, with 12 miles of single track. The former is an elevated line, running alongside the Liverpool docks, and the latter are all tube railways.

In America there are the elevated railways in New York, Brooklyn, Boston, and Chicago, amounting to about 250 miles in all; the Albany and Hudson line, having a length of about 40 miles; and the Nantasket Beach electric railway, with its 18 miles of single track.

In France the Paris Metropolitan, and the Paris-Orleans lines, have each about 8¾ miles of single track, while in Germany the Berlin Elevated and Underground Railway, and the Berlin-Wannsee Railway, have each about 7 miles of single track.

In Italy the Mediterranean Railway Co. is working a line from Milan to Varese, a distance of about 36 miles; the Adriatic Railway Co. has recently equipped the Lecco-Colico line, amounting to about 66 miles of single track; the Burgdorf-Thun Railway is about 25 miles long, and the Valtellina line will, when opened, have a length of about 67 miles.

With the exception of the three last-named lines, which employ three-phase alternating current motors, all the above use direct current motors, working at between 500 and 600 volts.

Present Systems of Working.—It is of far greater importance on electric railways, than on electric tramways, that not only should a uniform system be adopted, but that it should be one which is applicable, equally well, to main line and suburban traffic. The conditions to be met, however, when trains run at, say, half-hourly intervals, and at express speed, for perhaps a hundred miles without a stop,

are quite different to those under which suburban traffic is carried on, with trains every few minutes, and with only short distance runs.

The systems at present in use for supplying current to electric railways are—(1) By means of direct current generation and transmission, at between 500 and 650 volts, directly to the motors, through an insulated third rail, the track rails being used as the return. This system is employed on the Chicago and Boston Elevated Railways, the Liverpool Overhead Railway, the City and Waterloo Railway, and the Paris and Berlin lines.

(2) By means of direct current generation, at about 1,000 volts, with a three-wire distribution, the two conductor bars, on the up and down tracks, being at 1,000 volts pressure between themselves, each being 500 volts above, or below, the rails. This system * is employed only on the City and South London railway, which is, at the same time, the pioneer of all tube railways, and a most successful example of three-wire work.

(3) By the use of three-phase alternating current generation, at high pressure, with direct current distribution from local sub-stations, through the medium of rotating transformers. From the sub-station the direct current is taken and used as in (1). This method is in operation on the New York Elevated Railway, the Central London Railway, the Albany and Hudson Railway, the Milan-Varese Railway, and will be used on the Metropolitan and District Railways, London, when the reconstruction is complete.

(4) By the use of three-phase alternating currents, generated and distributed, generally at high pressure,

* The feeders to the London Bridge and Angel sub-stations work at 2,000 volts, and the pressure is lowered to 1,000 volts, at those points, by motor-generator "reducers."

directly to the motors. This system is at work on the Lecco-Colico, the Burgdorf-Thun, and the Valtellina Railways. It is also the one which was proposed for the electrification of the Metropolitan and District Railways, London, by Messrs. Ganz and Co., in opposition to method No. (3).

It will be seen that, so far as the line and the rolling stock are concerned, the first three methods are identical, in the employment of 500 volt direct current motors, an insulated third rail for one of the conductors, and the track rails for the return. The merits of both direct current generation and distribution, and of three-phase generation with rotating transformers, have been discussed earlier in this book, and, in their application to electric railways, there is nothing out of the ordinary.

But, while a sub-station, with transforming apparatus of a moving nature, necessitating the employment of attendants, may be justifiable for working the heavy traffic of suburban lines, it is another matter altogether when main lines are considered. The distance which can be fed economically, at low pressure, from any sub-station, is, perhaps, not more than about five miles in any direction. This gives the maximum distance apart for the sub-stations as about 10 miles. The number of main line express trains, which would be taking current from any sub-station at one time, would probably be not more than one, and then, for a considerable period, the output from the sub-station would be practically nothing. Under such conditions, the cost of operating the sub-station, per unit sent out, would be very high, although, for heavy continuous local traffic, it would probably be the best arrangement which has yet been devised.

Difference between Local and Main Line Traffic. — A

number of systems have been proposed for operating main line trains, and these we will deal with later. For the moment we will consider the difference between the conditions of working local and long distance traffic.

In travelling from one station to another, the different periods of the journey may be divided up somewhat as follows, viz.:—(1) Standing in the station. (2) Starting and accelerating. (3) Running at full speed. (4) Braking. For local traffic—(1) is quite an important consideration, particularly when the distance between the stations is not great, as much as 10 per cent. of the total time, occupied on the journey, often being taken up while waiting in the stations. The shorter the distance between the stations, the more important also are the accelerating (2) and braking (4) facilities. A high rate of acceleration, with powerful brakes, means that a high average rate of speed can be maintained, since much less time is wasted in getting up to the full speed, and in bringing the train to rest.

With steam traction the rate of acceleration seldom reaches more than ·5 ft. per second per second, but, with electric traction, an average of 3 ft. per second per second is not only possible, but is now actually accomplished, in everyday work, on the Liverpool Overhead Railway. On this line the average rate of speed, including stoppages at stations 730 yds. apart, is as high as 19 miles per hour.

The saving of time on a journey, due to quick acceleration and braking, means a saving of money, and the electric motor easily beats the steam locomotive in this particular. The entire conversion of the whole of our heavy suburban train service, from steam to electricity, is only a matter of time, for this very reason.

But, when we come to main line traffic, with its long runs and infrequent stops, the time taken, in accelerating

and braking, is of small importance, when compared with the ability to run at high rates of speed for long distances, and the electric motor, so far, has not proved its superiority to the steam locomotive in this respect. The future may show reasons for the displacement of the steam engine, on main lines, by the electric motor, but, at present, the advantages to be gained are too slight to warrant the change.

The Third Rail.—With the exception of those lines which have been mentioned already, as using high tension three-phase currents directly on the motors, and employing overhead wires, in order to prevent the possibility of accident through personal contact with the conductors, all electric railways use a third rail to convey the current to the motors. This rail usually consists of channelled steel, and is carried upon insulators, fixed either to the sleepers between the rails of each track, on short pillars between the two tracks, or at the sides of the tracks. Contact is made, with this rail, by cast-iron rubbing shoes, carried upon insulated spring supports.

Locomotives *v.* **Motor Cars.**—Following the example of steam, practically all the early electric lines use an independent locomotive, in front of the train of carriages. This locomotive is equipped with motors, generally mounted directly upon the wheel axles, and operating without gearing. Upon the locomotive are also carried the large controllers and resistances, for operating the motors.

These locomotives, while not so heavy as a steam locomotive of similar power, oftentimes carry more weight upon each of the wheels, since the number of wheels is much smaller. The ordinary steam locomotive, with its tender, would probably weigh about 45 tons, and would be carried on at least 14 wheels. This makes an average of

about 3 tons per wheel. An electric locomotive, weighing 45 tons, would be carried on only 8 wheels, with an average weight of $5\frac{1}{2}$ tons per wheel. This excessive weight, while quite necessary to produce the adhesion required for starting, and for rapid acceleration, is very liable to cause track troubles, such as loosened joints, etc., as well as vibration. On the Central London Railway it has been decided to abandon electric locomotives for these reasons, and to use, instead, what has proved to be the much more satisfactory method of motors on the carriages, with a multiple unit system of control, such as was described in Chap. VI.

By the use of the multiple unit system, which, with the exception of the electric railways in London, is practically universal, there is a great reduction in the weight upon any pair of wheels; the whole weight of the train is available for adhesion; trains of any length can be made up, without considering the motive power, since each car carries its own motors; the train can be driven from either end, or from either carriage; and no shunting is necessary, such as must be done when a locomotive is used, to bring it to the front of the train for each return journey.

In the multiple unit system each car has its own contact shoes, generally one at either end, and special flexible cables are employed to couple up one car with the next, to complete the controller circuits.

Another advantage which the multiple unit system has over the separate locomotive, is in connection with the working of a line having level crossings. Such crossings are not to be desired at any time, but, on many country lines, it is hardly possible to avoid them. As ordinary vehicular and pedestrian traffic have to pass over, it is impossible to carry a live third rail across as well.

If an electric locomotive were used, it could not get any

supply of current at such a place, and the train would have to coast through, for a distance of, perhaps, from 30 to 50 feet. But, with the multiple unit system, and two contact shoes on every car, it is certain that the contacts on the front car would have passed the break, and reached the farther conductor rail, before the last car had got up to the crossing. This method is employed on the Albany and Hudson line, and is very successful in operation. The country people use the level crossings there without danger, and the train service is carried on without the slightest difficulty, although there are no fences or gates.

Lighting Car Lamps in Tunnels.—On the electric railway in Berlin, which is partly an elevated and partly an underground line, an ingenious use has been made of the contact shoes, to switch the car lamps on automatically, as the trains enter the tunnels, and to switch them off again when they come into daylight. An auxiliary lamp switch is placed just above the contact shoe, in such a position, that, when the shoe is at its ordinary level, resting upon the conductor rail, the switch is not closed, and the lamps are not lit. In the tunnels the conductor rail is fixed a few inches higher than outside. This lifts the contact shoe far enough to put on the auxiliary lighting switch at the right instant. As a train enters the tunnel, the cars are illuminated, one after the other, when the various contact shoes reach the elevated rail.

Alternating Current Motors.—It was mentioned, earlier in this chapter, that, in the application of direct current motors to electric railways, there is no material difference to their use on tramways. But, when we come to alternating current motor systems, a new field is opened up.

Alternating current motors are of two kinds, those which work with single-phase currents, and those which use

multiphase currents. One of the disadvantages of the former class, is the smaller output obtained for any given size of machine, due to the fluctuating manner in which the power is necessarily applied, consisting, as it does, of a rapidly alternating current.

Multiphase motors have more of the qualities of direct current motors, so far as the uniform turning force which is applied to them. In Fig. 43, Chap. IV., was given a diagram showing three alternating currents, differing in phase by 120°, from which it will be seen that, at every instant, the motor is receiving from the mains a fairly constant amount of power. But, with a single-phase current, this would be first at a maximum, and then at zero, twice every complete alternation.

Synchronous Motors.—Alternating current motors may also be divided into two other classes, those which run synchronously with the alternations, and those which do not. A synchronous motor is practically identical with an ordinary alternating current generator, in that it has field magnets, excited by a direct current from an outside source, and an armature, which either receives, or generates, alternating currents. A synchronous motor is not self-starting, and it has to be brought up to synchronous speed before switching on to the mains. It is thus practically useless for the large majority of cases, particularly in connection with the direct application of power to a tramcar or a railway train, where starting and stopping are of frequent occurrence.

Induction Motors.—Non-synchronous motors are often called "induction" motors, and, sometimes, asynchronous motors. The term "induction motor" is probably the best to use, as it indicates very well the principle of the motor.

The induction motor has an armature * similar to that of the synchronous motor, but the field magnet system is quite different. Instead of having a series of alternate N. and S. poles, excited by a direct current, like that shown in Fig. 15, p. 47, the field system is similar to the armature, so far as it relates to the arrangement of the iron. That is to say, it is built up of laminated steel punchings, with a number of holes, or slots, around the periphery, in which the conductors are placed.

The field coils of small induction motors are wound with coils which are closed on themselves, and have no connection whatever with any outside circuit. In order, however, to keep down the heavy starting current, which such motors usually require, the larger sizes generally have the field coils divided up into a few groups, with the ends brought down to slip rings on the shaft, so that adjustable resistances may be inserted.

The armature is always fixed, and is commonly called the "stator." The field system revolves, and is called the "rotor." The current in the field coils is produced entirely by induction from the armature coils, in the same way as in the secondary circuit of a statical transformer. If the rotor were held stationary, the maximum current would be induced in its coils, and, if it revolved at synchronous speed, no current would be induced, since the rotor coils would be moving just as fast as the rotating magnetism of the armature coils.

The effect is very similar to that which would occur, if the armature and fields of a direct current motor were

* The terms "armature" and "field" are here applied to the stationary and revolving parts respectively of the induction motor, in the usually accepted sense, but, strictly speaking, neither term is the correct one.

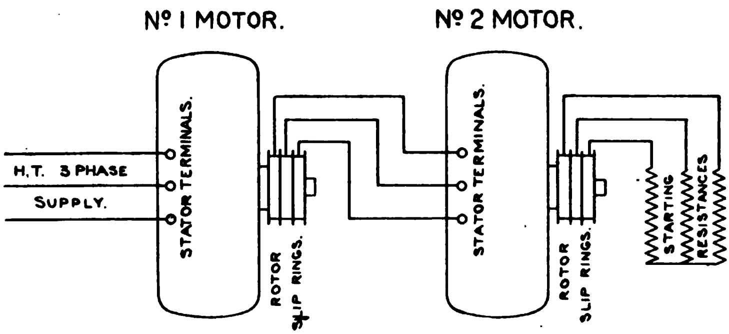
each capable of rotation. If the fields of such a motor were fully excited, and were rotated at full speed, while the armature was held at rest, a large current would be induced in the armature coils. The actual amount of current generated would depend entirely upon the relative motions of the field and the armature.

Speed of Induction Motors.—It will be seen, therefore, that an induction motor cannot run, as a motor, above synchronous speed. If it did, it would be doing work as a dynamo. It always runs at that speed, under synchronous speed, which is necessary to induce in its rotor sufficient current to produce the required torque to do the work at the moment. The difference between the actual speed of the rotor and synchronous speed is called the "slip." This slip would probably not exceed 2 per cent., when doing full load, which means that the induction motor maintains a fairly constant speed, throughout its normal range of work. This is quite different to the ordinary series-wound direct current motor, which, as will be seen from Fig. 52, p. 136, decreases considerably in speed as the load increases.

Variable speed can only be obtained by means of resistances. These are generally placed in circuit with the rotor coils, through the medium of the slip rings already mentioned, the greater the resistance used, the slower being the speed. The line current is often connected directly to the stator, and, as no moving contacts are used, high pressures can be employed without danger. This is a matter of considerable importance, as, with direct current motors, above 650 volts has not been practicable. The absence of any commutator, and of any high pressure moving contacts, are most important points in favour of the induction motor.

Fall of Pressure on Track Rails with Alternating Current.—As was mentioned earlier, three-phase currents are usually employed. These are conveyed to the moving train, either by three independent overhead conductors, or by two overhead conductors, with the rail as the return. In Chap. VIII. were given figures relating to the fall of pressure on track rails, but those figures only relate to direct currents. When alternating currents are used, the fall of pressure will depend also upon the periodicity, or

Fig. 189.



CASCADE CONNECTION OF TWO A. C. INDUCTION MOTORS.

number of complete alternations, and may easily amount to ten times as much as with direct currents. It is necessary, therefore, either to supplement the track rails with copper conductors, to reduce the current actually flowing in the rails, or to employ an insulated copper return rail, which may have a wearing surface of iron.

Cascade connection of A. C. Motors.—In dealing with the control of direct current motors, the economy of using a series connection for low speeds, and a parallel connection for high speeds, was pointed out. Such an arrangement,

however, is not yet possible with alternating induction motors, the nearest approach to it, which has been devised, being to use what is called the "cascade" connection. This is shown in Fig. 189, and consists of a special method of connecting up the motors, during the starting process.

Two motors are necessary. The first is connected with its stator directly to the line, while its rotor is connected up to the stator of the second motor. The rotor of the second motor is connected to starting resistances in the usual manner. This arrangement, like that of the series connection of two direct current motors, cannot be used for anything above half speed. But, while two direct current motors can be connected in parallel for higher speeds, the second induction motor has to be cut entirely out of the circuit at such times. This is a serious disadvantage, as, when the heavy work has to be done, only one motor is available. It may be said, why not join up the stator of the second motor to the line, and use it as well as the first one? This can only be done, however, when both the stator and the rotor are wound for the same pressures. In practice it would not be possible to wind the rotors for anything but a comparatively low pressure, while a high pressure is the only one economically possible for the line.

To obviate the disadvantage of having one half of the motive power on the train out of service, the two motors have sometimes been made of unequal powers, the motor which is cut out being only of small size, and intended only for help during the starting.

Advantages of High Line Pressure.—The system in use on the Burgdorf-Thun, and other three-phase lines, is similar to the one just described. Transformers are sometimes used on the train, in order to reduce the pressure at

the motors, but this depends largely upon the actual line voltage used. Pressures up to 2,000 or 3,000 volts would be quite safe for the motors, but, to obtain the full advantages for long distance working, a higher pressure on the line is necessary, not only because of the economy in the conductors themselves, but also to reduce the actual amount of current which has to be collected by the sliding or rolling contact. At 500 volts pressure, the current, necessary for starting and accelerating a heavy train, may easily amount to over 1,000 ampères, and it is a matter of serious difficulty to collect such a current properly. As the current decreases in the inverse ratio to the rise of pressure, for the same power, it will be seen that the advantage of using a high line pressure is very great.

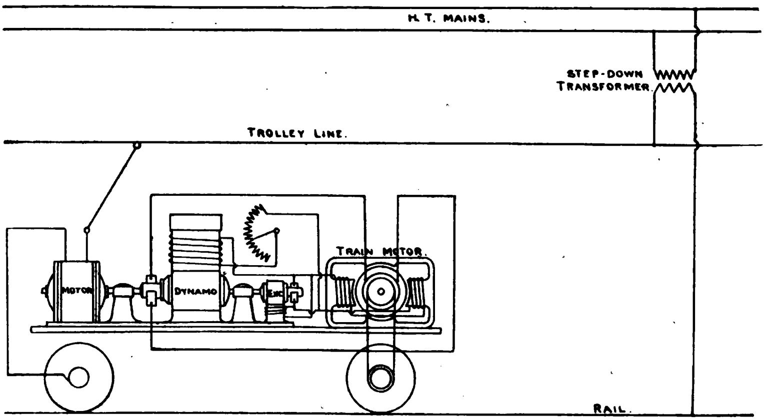
D. C. *v.* A. C. Motors.—Comparing the three-phase induction motor with the ordinary direct current series motor, it is evident that the former is not nearly so applicable for short distance traffic as the latter. The induction motor is deficient in the power of rapid acceleration, and one of its great features, that of practically constant speed, becomes a drawback, when applied to a service which calls for frequent starting and stopping. For long runs, at uniform speed, it is very suitable, as the comparatively few stopping places, on main lines, are not sufficient to make its accelerating imperfections of any great importance.

Advantages of Simple System.—Three-phase lines require three conductors, and, although these may consist of only two overhead and one on the track, yet, at all crossings and junctions, considerable complication is bound to result, since the two overhead conductors have the full line pressure between them, as well as between each and the rail. The simplest possible system, and one which it is worth sacrificing a great deal to retain, would be to

use only one overhead conductor, in addition to the rail return, as there would be no more electrical difficulty, at junctions and crossings, than with the overhead construction of an ordinary street tramway.

A number of systems have been proposed, in which only one overhead conductor is required, but, up to the present, excepting for the ordinary 500 volt supply, none have yet

Fig. 190.



WARD LEONARD SYSTEM FOR SINGLE-PHASE RAILWAY WORKING.

come into practical use. Some of the systems, however, are of great technical interest, and may contain the germs of the future system which is bound to come, sooner or later, before electric railways can become universal.

Single-Phase A. C. Motor Generator System. — Messrs. Mordey and Jenkin, in a paper recently read before the Institution of Civil Engineers,* laid down a number of requirements for a general system, and, by a process of elimination, arrived at the following conclusions. (1) That

* See *Journal Inst. Civil Engineers,* Vol. cxlix, 1901–2, Part III.

for main line trains an extra high pressure transmission should be used, and that the generators should be alternators giving single-phase currents. (2) That the substations should contain no moving machinery, in order to remove the necessity of constant attention or supervision. (3) That a single-phase overhead conductor, with a return rail at the earth's potential, should be used.

To get over the difficulty of using a single-phase induction motor, for the direct propulsion of the train, they suggested a modification of the system originally proposed by Mr. Ward Leonard, in 1891. The arrangement is illustrated in Fig. 190. The locomotives carry a single-phase self-starting induction motor, which is coupled to a direct current dynamo, and to an independent exciter. The train motors would also be of the direct current type, carried either upon the locomotive itself, or under the carriages, as in the multiple unit system. The primary mains would be laid underground, and would feed into statical transformers, placed at convenient positions along the track. These transformers would feed directly into the overhead conductor and the rails. The induction motor would be started, once for all, on any journey, and, unless the exciter were connected, the dynamo would run idle, without giving any current.

The exciter is used to excite both the dynamo and the train motors. Instead of having to work an elaborate controller, with main circuit resistances, the whole control of the train would be done by the excitation of the dynamo. As the motors, when starting, require only a small pressure, the dynamo would be excited just sufficiently to give this, and the excitation would be gradually increased, in order to speed the motors up.

In this way the complete control of the train is possible

without any appreciable loss in regulating resistances, since the voltage of the dynamo is adjusted to supply the proper current to the motors. To reverse the direction of the motion, either the field of the dynamo or the fields of the train motors must be reversed, but all the operations can be done by field adjustment alone. The effect of this system is to give us a variable ratio gear, which works entirely without jerks or irregularities of any kind. If its mechanical counterpart could be devised, it would be of immense value.

Another advantage which this proposed system would have, is in enabling energy to be returned to the line, when the train is running down an incline, or when braking. The ordinary series motor, worked from a supply at constant pressure, cannot do this, and the energy is always absorbed in resistances. But, on a line with a number of gradients, we should obtain great economy, if the energy of a descending train could be utilized in helping another train to ascend.

There are, of course, a number of difficulties in the way of such a system as the one just described. To take the large current necessary for starting the train, from a dynamo with a very weak field, would be most likely to cause serious trouble from sparking. The large amount of machinery which has to be carried, viz. the induction motor, the dynamo, the exciter, and the train motors, either of which (with the exception of the exciter) must be large enough to drive the train, is a great drawback, as the additional weight would be very considerable. While most ingenious and interesting, it is doubtful whether its complications would not more than outweigh its very evident advantages.

Single-phase A. C. Series Motor System.—In a paper

presented to the American Institution of Electrical Engineers, in Sept. 1902, Mr. B. G. Lamme has gone a step farther than Messrs. Mordey and Jenkin. By a somewhat similar process of deduction, he arrives at the same conclusions with regard to a general system, but, in applying this system, he proposes to use single-phase, alternating current, series-wound motors on the train, just as one uses direct current motors at the present time. In fact, it is stated in the paper, that the Washington, Baltimore, and Annapolis railway, which extends for about 46 miles outside Washington, is now being equipped with such a system, and that it will be in actual work before long.

One of the very earliest alternating current motors, for single-phase currents, was an ordinary direct current motor with laminated field-magnets. Such a motor will, of course, run, but, with the high periodicities formerly in use (100 cycles and over), great trouble was experienced from sparking, and a small output only could be obtained, on account of the high self-induction of the machine. But whether such a motor is practicable, with the low periodicity of 16⅔ cycles per second proposed for this line, is another matter, and one which only experience can prove. Mr. Lamme states that several motors of this type, built by the Westinghouse Co., have been tested, with very satisfactory results, and, if practical working only bears out this statement, the problem of long distance railway work may almost be said to be solved. The subject is one of such great importance, that the experiments upon this railway will be watched with the utmost interest, mixed with not a little admiration at the pluck of the engineers, in attempting such an expensive experiment, which, after all, is the only way of proving the system.

Direct Current Series System.—Another system which

has been suggested is that of using a constant current, with direct current motors in series. By this is meant, not only that the motors on any one train are in series with each other, but that the trains themselves are in series. To carry out such a system, two insulated conductors are necessary throughout the line, and these must be divided into sections, which are insulated from each other. At the end of each section there would be a switch, to connect it to the next section, and if a section have no train in it, it must be short-circuited, or otherwise the circuit would be broken.

With such a system the torque would be constant, since the current is constant, but it could be varied at will by shunting the field of the motors. The difficulties of the system would be great, not only in the insulation of the motors, if a high pressure be used, but in the automatic section switches, and in the generating plant. Two distinct conductors must be employed, as the rail return would not be available. Neither would it be possible for more than one train to be in one section at a time, without reducing the current, taken by each train, to half the amount. As the current is constant, the losses, due to the line resistance, would also be a constant, and, although this would not be serious, if a large number of trains were running, yet it is quite possible for it to amount to a considerable quantity, at certain times. It is not, however, likely that such a system will ever come into practical use, although it has received the commendation of high authority.

Future of Electric Railways.—The descriptions given in this chapter of the systems of electric traction for railway purposes, both in use and proposed, have necessarily been of an incomplete nature. The whole question of railway

traffic is in a transition state. The competition of electric tramways, in the immediate neighbourhood of suburban steam lines, has shown, with no uncertainty, that unless electric traction be applied also to them, their traffic is bound to decrease, and their income with it.

The electrification of suburban lines must be carried out within the next few years, or the lines, as we now know them, must cease to exist. With regard, however, to main lines, it is a different matter, and, while one or other of the systems described may prove to be the right one, there is not, at the moment, enough experience to warrant any railway company in throwing on one side its large and expensive stock of steam locomotives, in order to equip with electricity. But that it will come in time there can be no doubt. Meanwhile, whatever may be said of main lines, there is no excuse for delay in the electrification of suburban lines.

APPENDIX

REGULATIONS OF THE BOARD OF TRADE

THE Board of Trade has power, whether under the special Acts or Provisional Orders of Tramway Undertakers, to issue Regulations and Bye-Laws to be observed by the Undertakers. These, as regards the use of power, whether electric or otherwise, vary to some extent according to the circumstances of each case; but a special code of regulations, which are of general application where electric power is used, was issued by the Board of Trade in March 1894, and modified in 1901 and 1902. They are as follows:—

*Regulations made by the Board of Trade under the Provisions of the ———— Tramways * Act, for regulating the employment of insulated returns, or of uninsulated metallic returns of low resistance; for preventing fusion or injurious electrolytic action of or on gas or water pipes or other metallic pipes, structures, or substances; and for minimizing as far as is reasonably practicable injurious interference with the electric wires, lines, and apparatus of parties other than the Undertakers, and the currents therein, whether such lines do or do not use the earth as a return.*

* A different set of regulations is issued in the case of railways constructed underground in metal-lined tunnels. See p. 429.

Definitions.

In the following regulations—

The expression "energy" means electrical energy.

The expression "generator" means the dynamo or dynamos or other electrical apparatus used for the generation of energy.

The expression "motor" means any electric motor carried on a car and used for the conversion of energy.

The expression "pipe" means any gas or water pipe or other metallic pipe, structure or substance.

The expression "wire" means any wire or apparatus used for telegraphic, telephonic, electrical signalling, or other similar purposes.

The expression "current" means an electric current exceeding one thousandth part of one ampère.

The expression "the Company" has the same meaning as in the Tramways Act.

Regulations.

1. Any dynamo used as a generator shall be of such pattern and construction as to be capable of producing a continuous current without appreciable pulsation.*

2. One of the two conductors used for transmitting energy from the generator to the motor shall be in every case insulated from earth, and is hereinafter referred to as the "line"; the other may be insulated throughout, or may be uninsulated in such parts and to such extent as is provided in the following regulations, and is hereinafter referred to as the "return."

3. Where any rails on which cars run or any conductors laid between or within three feet of such rails form any part of a return, such part may be uninsulated. All other returns or parts of a return shall be insulated, unless of such sectional

* The Board of Trade will be prepared to consider the issue of regulations for the use of alternating currents for electrical traction on application.

area as will reduce the difference of potential between the ends of the uninsulated portion of the return below the limit laid down in Regulation 7.

4. When any uninsulated conductor laid between or within three feet of the rails forms any part of a return, it shall be electrically connected to the rails at distances apart not exceeding 100 ft. by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or by other means of equal conductivity.

5. When any part of a return is uninsulated it shall be connected with the negative terminal of the generator, and in such case the negative terminal of the generator shall also be directly connected, through the current-indicator hereinafter mentioned, to two separate earth connections which shall be placed not less than 20 yards apart.

Provided that in place of such two earth connections the (Corporation or) Company may make one connection to a main for water supply of not less than three inches internal diameter, with the consent of the owner thereof and of the person supplying the water, and provided that where, from the nature of the soil or for other reasons, the (Corporation or) Company can show to the satisfaction of an inspecting officer of the Board of Trade that the earth connections herein specified cannot be constructed and maintained without undue expense, the provisions of this regulation shall not apply.

The earth connections referred to in this regulation shall be constructed, laid, and maintained so as to secure electrical contact with the general mass of earth, and so that an electromotive force, not exceeding four volts, shall suffice to produce a current of at least two ampères from one earth connection to the other through the earth, and a test shall be made at least once in every month to ascertain whether this requirement is complied with.

No portion of either earth connection shall be placed within six feet of any pipe, except a main for water supply of not less than three inches internal diameter, which is metallically con-

nected to the earth connections with the consents hereinbefore specified.

When the generator is at a considerable distance from the tramways, the uninsulated return shall be connected to the negative terminal of the generator by means of one or more insulated return conductors, and the generator shall have no other connection with earth; and in such case the end of each insulated return connected with the uninsulated return shall be connected also through a current indicator to two separate earth connections, or with the necessary consents to a main for water supply, or with the like consents to both in the manner prescribed in this regulation.

If the current indicator cannot conveniently be placed at the connection of the uninsulated return with the insulated return, this instrument may consist of an indicator at the generating station connected by insulated wires to the terminals of a resistance interposed between the return and the earth connection or connections. The said resistance shall be such that the maximum current laid down in Regulation 6 (i) shall produce a difference of potential not exceeding one volt between the terminals. The indicator shall be so constructed as to indicate correctly the current passing through the resistance when connected to the terminals by the insulated wire before mentioned.

6. When the return is partly or entirely uninsulated the (Corporation or) Company shall in the construction and maintenance of the tramway (A) so separate the uninsulated return from the general mass of earth, and from any pipe in the vicinity; (B) so connect together the several lengths of the rails; (C) adopt such means for reducing the difference produced by the current between the potential of the uninsulated return at any one point and the potential of the uninsulated return at any other point; (D) so maintain the efficiency of the earth connections specified in the preceding regulations as to fulfil the following conditions, viz.:—

(i.) That the current passing from the earth connections

through the indicator to the generator or through the resistance to the insulated return shall not at any time exceed either two ampères per mile of single tramway line or five per cent. of the total current output of the station.

(ii.) That if at any time and at any place a test be made by connecting a galvanometer or other current-indicator to the uninsulated return and to any pipe in the vicinity, it shall always be possible to reverse the direction of any current indicated by interposing a battery of three Leclanché cells connected in series if the direction of the current is from the return to the pipe, or by interposing one Leclanché cell if the direction of the current is from the pipe to the return.

In order to provide a continuous indication that the condition (i.) is complied with, the (Corporation or) Company shall place in a conspicuous position, a suitable, properly connected, and correctly marked current-indicator, and shall keep it connected during the whole time that the line is charged.

The owner of any such pipe may require the (Corporation or) Company to permit him at reasonable times and intervals to ascertain by test that the conditions specified in (ii.) are complied with as regards his pipe.

7. When the return is partly or entirely uninsulated a continuous record shall be kept by the (Corporation or) Company of the difference of potential during the working of the tramway between points on the uninsulated return. If at any time such difference of potential between any two points exceeds the limit of seven volts, the (Corporation or) Company shall take immediate steps to reduce it below that limit.

8. Every electrical connection with any pipe shall be so arranged as to admit of easy examination, and shall be tested by the (Corporation or) Company at least once in every three months.

9. Every line and every insulated return or part of a return except any feeder shall be constructed in sections not exceeding one-half of a mile in length, and means shall be provided for isolating each such section for purposes of testing.

10. The insulation of the line and of the return when insulated, and of all feeders and other conductors, shall be so maintained that the leakage current shall not exceed one-hundredth of an ampère per mile of tramway. The leakage current shall be ascertained daily before or after the hours of running when the line is fully charged. If at any time it should be found that the leakage current exceeds one-half of an ampère per mile of tramway the leak shall be localized and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localized and removed within 24 hours. Provided that where both line and return are placed within a conduit this regulation shall not apply.

11. The insulation resistance of all continuously insulated cables used for lines, for insulated returns, for feeders, or for other purposes, and laid below the surface of the ground, shall not be permitted to fall below the equivalent of 10 megohms for a length of one mile. A test of the insulation resistance of all such cables shall be made at least once in each month.

12. Where in any case in any part of the tramway the line is erected overhead and the return is laid on or under the ground, and where any wires have been erected or laid before the construction of the tramway in the same or nearly the same direction as such part of the tramway, the (Corporation or) Company shall, if required so to do by the owners of such wires or any of them, permit such owners to insert and maintain in the (Corporation or) Company's line one or more induction coils or other apparatus approved by the (Corporation or) Company for the purpose of preventing disturbances by electric induction. In any case in which the (Corporation or) Company withhold their approval of any such apparatus the owners may appeal to the Board of Trade, who may, if they think fit, dispense with such approval.

13. Any insulated return shall be placed parallel to and at a distance not exceeding three feet from the line when the line and return are both erected overhead, or eighteen inches when they are both laid underground.

14. In the disposition, connections, and working of feeders the (Corporation or) Company shall take all reasonable precautions to avoid injurious interference with any existing wires.

15. The (Corporation or) Company shall so construct and maintain their system as to secure good contact between the motors and the line and return respectively.

16. The (Corporation or) Company shall adopt the best means available to prevent the occurrence of undue sparking at the rubbing or rolling contacts in any place and in the construction and use of their generator and motors.

17. In working the cars the current shall be varied as required by means of a rheostat containing at least twenty sections, or by some other equally efficient method of gradually varying resistance.

18. Where the line or return or both are laid in a conduit, the following conditions shall be complied with in the construction and maintenance of such conduit:—

(*a*) The conduit shall be so constructed as to admit of examination of and access to the conductors contained therein and their insulators and supports.

(*b*) It shall be so constructed as to be readily cleared of accumulation of dust or other *débris*, and no such accumulation shall be permitted to remain.

(*c*) It shall be laid to such falls and so connected to sumps or other means of drainage, as to automatically clear itself of water without danger of the water reaching the level of the conductors.

(*d*) If the conduit is formed of metal, all separate lengths shall be so jointed as to secure efficient metallic continuity for the passage of electric currents. Where the rails are used to form any part of the return they shall be electrically connected to the conduit by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or other means of equal conductivity, at distances apart not exceeding 100 feet. Where the return is wholly insulated and contained within the conduit, the latter shall be connected to

earth at the generating station or sub-station through a high-resistance galvanometer suitable for the indication of any contact or partial contact of either the line or the return with the conduit.

(*e*) If the conduit is formed of any non-metallic material not being of high insulating quality and impervious to moisture throughout, the conductors shall be carried on insulators the supports for which shall be in metallic contact with one another throughout.

(*f*) The negative conductor shall be connected with earth at the generating station or sub-station by a voltmeter, and may also be connected with earth at the generating station or sub-station by an adjustable resistance and current indicator. Neither conductor shall otherwise be permanently connected with earth.

(*g*) The conductors shall be constructed in sections not exceeding one-half a mile in length, and, in the event of a leak occurring on either conductor, that conductor shall at once be connected with the negative pole of the dynamo, and shall remain so connected until the leak can be removed.

(*h*) The leakage current shall be ascertained daily, before or after the hours of running, when the line is fully charged, and if at any time it shall be found to exceed one ampère per mile of tramway the leak shall be localized and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localized and removed within 24 hours.

19. The (Corporation or) Company shall, so far as may be applicable to their system of working, keep records as specified below. These records shall, if and when required, be forwarded for the information of the Board of Trade :—

Daily Records.

No. of cars running.
Maximum working current.
Maximum working pressure.

Maximum current from the earth connections—(*vide* Regulation 6 (i.).

Leakage current—(*vide* Regulations 10 and 18 (*h*).

Fall of potential in return—*vide* Regulation 7.

Monthly Records.

Condition of earth connections—*vide* Regulation 5.

Insulation resistance of insulated cables—*vide* Regulation 11.

Quarterly Records.

Conductance of joints to pipes—*vide* Regulation 8.

Occasional Records.

Any tests made under provisions of Regulation 6 (ii.).

Localization and removal of leakage, stating time occupied.

Particulars of any abnormal occurrence affecting the electric working of the tramway.

REGULATIONS MADE BY THE BOARD OF TRADE AS REGARDS ELECTRICAL POWER (OVERHEAD TROLLEY SYSTEM) ON THE TRAMWAYS

The Board of Trade, under and by virtue of the powers conferred upon them in this behalf, do hereby make the following regulations for securing to the public reasonable protection against danger in the exercise of the powers conferred by Parliament with respect to the use of electrical power (overhead trolley system) on all or any of the tramways on which the use of mechanical power has been authorized by the Tramways Order, and they also order that the said regulations be substituted for all other regulations in this behalf contained in any Tramway Act or Tramway Order confirmed by Act of Parliament:

And the Board of Trade do also hereby make the following bye-laws with regard to all or any of such tramways worked on the overhead trolley system.

Regulations.

1. Every motor carriage used on the tramways shall comply with the following requirements, that is to say:—

(*a*) It shall be fitted with an apparatus to indicate to the driver the speed at which it is running.

(*b*) The wheels shall be fitted with brake blocks, which can be applied by a screw or treadle, or by other means, and there shall be in addition an adequate electric brake.

(*c*) It shall be fitted, if and when required by the Board of Trade, with a governor which cannot be tampered with by the driver, and which shall operate so as to cut off all electric current from the motors whenever the speed exceeds *ten* miles an hour.

(*d*) It shall be numbered inside and outside, and the number shall be shown in conspicuous parts thereof.

(*e*) It shall be fitted with a suitable fender, which will act efficiently as a life protector, and with a special bell or whistle to be sounded as a warning when necessary.

(*f*) It shall be so constructed as to enable the driver to command the fullest possible view of the road before him.

(*g*) It shall be free from the clatter of machinery, such as to constitute any reasonable ground of complaint, either to the passengers or to the public.

2. No trailing carriage shall be used on the tramways.

3. Every carriage used on the tramways shall be so constructed as to provide for the safety of passengers, and for their safe entrance to, exit from, and accommodation in such carriage, and for their protection from the apparatus used for drawing or propelling the carriage.

4. Every carriage on the tramways shall, during the period between one hour after sunset and one hour before sunrise or during fog, carry a lamp so constructed and placed as to exhibit a white light visible within a reasonable distance to the front, and every such carriage shall carry a lamp so constructed and placed as to exhibit a red light visible within a reasonable distance to the rear.

5. The Board of Trade and their officers may, from time to time, and shall, on the application of the local authority of any of the districts through which the said tramways pass, inspect the carriages used on the tramways, and the working arrangements generally, and may, whenever they think fit, prohibit the use on the tramways of any of them which, in their opinion, are not safe for use.

6. The speed at which the carriages shall be driven or propelled along the tramways shall not exceed the rate of *eight* *

* This has been raised to *twelve* miles in some cases.

miles an hour, and the speed at which the carriages shall pass through facing points, whether fixed or movable, shall not exceed the rate of *four* miles an hour.

7. The passengers shall not have access to any portion of the electric circuit.

8. All electric mains, leads and connections used must be of ample size, and must be thoroughly insulated and protected by safety fuses or other cut-outs which will operate to break the circuit before the current has risen to an amount which would cause any injurious heating of the conductors, and the length of any safety fuse in the clear shall not be less than two inches.

9. The electrical pressure or difference of potential between any suspended conductors used in connection with the working of the tramways by electrical power and the earth, or between any two such suspended conductors, shall in no case exceed 550 volts continuous pressure.

10. The suspended conductors used in connection with the working of the tramways by electrical power shall be securely attached to supports, the intervals between which shall not, except with the approval of the Board of Trade, exceed 120 feet, and they shall be in no part at a less height from the surface of the street than 17 feet, except where they pass under railway bridges.

11. The line wire shall be divided up into sections not exceeding (except with the special approval of the Board of Trade) one-half of a mile in length, between every two of which shall be inserted an emergency switch, which apparatus shall be so enclosed as to be inaccessible to pedestrians.

12. The sectional area of the conductor in any electric line laid or erected in any street shall not be less than the area of a circle of one-tenth of an inch diameter, and where the conductor is formed of a strand of wires, each separate wire shall be at least as large as No. 20 standard wire gauge: Provided that this regulation shall not apply to any electric line connected to the rails for the purpose of measuring the fall of

potential in the return and not otherwise connected with the electric circuit.

13. No part of any electric line shall be used for the transmission of more than 300,000 watts, except with the consent in writing of the Board of Trade, and efficient means shall be provided to prevent this limit being at any time exceeded.

14. The electrical energy supplied through feeders shall not be generated at or transformed to a pressure higher than 650 volts, except with the written consent of the Board of Trade, and subject to such regulations and conditions as they may prescribe.

15. All electrical conductors fixed upon the carriages in connection with the "trolley wheel" shall be formed of flexible cables protected by indiarubber insulation of the highest quality, and additionally protected wherever they are adjacent to any metal so as to avoid risk of the metal becoming charged.

16. The trolley standard of every double-decked carriage shall be electrically connected to the wheels of the carriage in such manner as to prevent the possibility of this standard becoming electrically charged from any defect in the electrical conductors contained within it.

17. An emergency cut-off switch shall be provided and fixed so as to be conveniently reached by the driver in case of any failure of action of the controller switch.

18.[1] Efficient guard wires shall be erected and maintained at all places where telegraph or telephone wires cross above the electric conductors of the tramways.

19. Where any accident by explosion or fire, or any other accident of such kind as to have caused or to be likely to have caused loss of life or personal injury has occurred in connection with the electric working of the tramways, immediate notice thereof shall be given to the Board of Trade.

Penalty.

NOTE.—The Company or any other company or person

[1] See Special Regulations, p. 433.

using electrical power on the tramways contrary to any of the above regulations is, for every such offence, subject to a penalty not exceeding £10, and also in the case of a continuing offence, to a further penalty not exceeding £5 for every day during which such offence continues after conviction thereof.

Bye-laws.

1. The special bell or whistle shall be sounded by the driver of the carriage from time to time when it is necessary as a warning.

2. Whenever it is necessary to avoid impending danger, the carriages shall be brought to a standstill.

3. The entrance to and exit from the carriages shall be by the hindermost or conductor's platform.

4. The carriages shall be brought to a standstill immediately before reaching the following points. (Here is set out a list in each case.)

5. A printed copy of these regulations and bye-laws shall be kept in a conspicuous position inside of each carriage in use on the tramways.

Penalty.

NOTE.—Any person offending against or committing a breach of any of these bye-laws is liable to a penalty not exceeding forty shillings.

The provisions of the Summary Jurisdiction Acts, with respect to the recovery of penalties, are applicable to the penalties for the breach of these regulations or bye-laws.

Signed by Order of the Board of Trade this day of .

Assistant Secretary, Board of Trade.

BOARD OF TRADE REGULATIONS

Prescribed for regulating the employment of insulated returns, or of uninsulated metallic returns of low resistance; for preventing fusion or injurious electrolytic action of or on gas or water pipes or other metallic pipes, structures, or substances; and for minimizing, as far as is reasonably practicable, injurious interference with the electric wires, lines, and apparatus of parties other than the undertaking, and the currents therein, whether such lines do or do not use the earth as a return. *These Regulations only apply to railways constructed underground in metal-lined tunnels:—*

1. Any dynamo used as a generator shall be of such pattern and construction as to be capable of producing a continuous current without appreciable pulsation.

2. One of the two conductors used for transmitting energy from the generator to the motors shall be in every case insulated from earth by means of insulators of a strong and durable material, so shaped as to offer great resistance to surface leakage, and is hereinafter referred to as the "line"; the other may be similarly insulated throughout, or may be uninsulated in such parts and to such extent as is provided in the following regulations, and is hereinafter referred to as the "return."

3. Where any rails on which trains run or any conductors laid within the metal-lined tunnels in which the railway is constructed form any part of a return, such part may be uninsulated. All other returns or parts of a return shall be insulated.

4. When any uninsulated conductor forms any part of a return, it shall be electrically connected to the rails at distances apart not exceeding 100 feet by means of copper strips having

a sectional area of at least one-sixteenth of a square inch, or by other means of equal conductivity.

5. When any part of a return is uninsulated it shall be connected with the negative terminal of the generator, and in such case the negative terminal of the generator shall also be directly connected to the iron or other metal plates forming the lining of the tunnels unless this lining is otherwise connected to the rails. In each case the connection shall be made through a suitable current indicator.

6. The iron or other metal plates forming the lining of the tunnels shall be so made and connected together as to form a continuous metal tube.

7. Where any pipe is brought into the tunnel from outside, except any pipe belonging to the company which is not in metallic connection with or laid within six feet of any other pipe, means shall be provided to secure that no portion of the pipe outside the metal tube shall be in metallic connection with the tube or with any conductor of electricity within the tube.

8. When the rails form any part of the return they shall either be electrically connected, at intervals not exceeding 100 feet, to the metal tube by metallic conductors which will not be appreciably heated by a current of 100 ampères, or they shall not be in any metallic connection with the metal tube except by means of the connections to the negative terminal of the generator. In the latter case the rails shall be supported by cross sleepers of wood specially prepared to resist the penetration of moisture and the growth of any mould or fungus, and they shall be of such sectional area and so connected at joints and from one line of rails to another, and where necessary to supplementary conductors or feeders, that the difference of potential between the rails and the metal tube shall not in any part and under any working conditions exceed 10 volts. A test shall be made at least once in each month.

9. When the return is partly or entirely uninsulated a daily

record shall be kept by the company of the difference of potential during the working of the railway between the points of the uninsulated return furthest from and nearest to the generating station at the time when the load is greatest. If at any time such difference of potential exceeds the limit of seven volts, the company shall take immediate steps to reduce it below that limit.

10. Every line and every insulated return shall be constructed in sections, and means shall be provided at or near each station for breaking the connection between sections for the rapid localization of faults.

11. The insulation resistance of any conductor laid outside the metal tube shall not be permitted to fall below the equivalent of 10 megohms for a length of one mile. A test shall be made at least once in each month.

12. The leakage current shall be tested daily before and after the hours of running with the working pressure, and duly recorded. Should the amount of this at any time appear to indicate a fault of insulation, steps shall at once be taken to localize and remove it.

13. The company shall, so far as may be applicable to their system of working, keep records as follows. These records shall be preserved for twelve months, and shall, if and when required, be forwarded for the information of the Board of Trade :—

Daily Records.—Number of trains running. Maximum working current. Maximum working pressure. Maximum current from the rails to generator. Maximum current from the metal tube to generator. Leakage current (*vide* Reg. 12). Fall of potential in return (*vide* Reg. 9).

Monthly Records.—Maximum difference of potential between rails and metal tube (*vide* Reg. 8). Insulation resistance of conductors laid outside metal tube (*vide* Reg. 11).

Occasional Records.—Localization and removal of leakage, stating time occupied. Particulars of any abnormal occurrence affecting the working of the railway.

Definitions. — The expression "generator" means the dynamo or dynamos or other electrical apparatus used for the generation of energy. The expression "motor" means any electric motor carried on a train and used for the conversion of energy. The expression "pipe" means any gas or water pipe or other metallic pipe, structure, or substance.

GUARD WIRES ON ELECTRIC TRAMWAYS.

BOARD OF TRADE REGULATION. (Sept. 1902.)

If and whenever telegraph or telephone wires, unprotected with a permanent insulated covering, cross above, or are liable to fall upon, or to be blown on to, the electric conductors of the tramways, efficient guard wires shall be erected and maintained at all such places.

Explanatory Memorandum.

Note.—The expression "telegraph wire" includes all telegraph and telephone wires.

For the purpose of this memorandum, telegraph wires are divided into two classes, namely :—

(*a*) Wires weighing less than 100 lbs. per mile.

(*b*) Wires weighing 100 lbs. or more per mile.

Each guard wire should be well earthed at one point at least, and at intervals of not more than five spans. The resistance to earth should be sufficiently low to insure that a telegraph or telephone wire falling on and making contact with the guard wire and the trolley wire at any time will cause the circuit breaker protecting that section to open.

The earth connection should be made by connecting the wire through the support to the rails by means of a copper bond. When first erected, the resistance to earth of the guard wires should be tested, and periodical tests should be made to prove that the earth connection is efficient.

Guard wires should be, in general, of galvanized steel, but in manufacturing districts in which such wires are liable to corrosion bronze or hard-drawn copper wires should be used.

The gauge of the guard wires should not be less than seven strands of No. 16 or one of No. 8 wire.

The supports for the guard wires should be rigid and of sufficient strength for their purpose, and at each support each guard wire should be securely bound in or terminated.

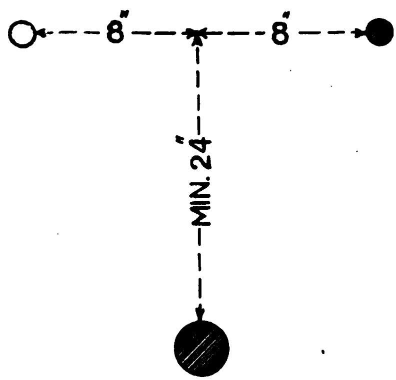
The rise of the trolley boom should be so limited that if the trolley leaves the wire it will not foul the guard wires.

TELEGRAPH WIRES CROSSING TROLLEY WIRES.

Class (a).—Wires weighing less than 100 lbs. per mile.

The guard wires may be of the cradle or hammock type,

Fig. 191.



GUARD WIRES OVER ONE TROLLEY WIRE.

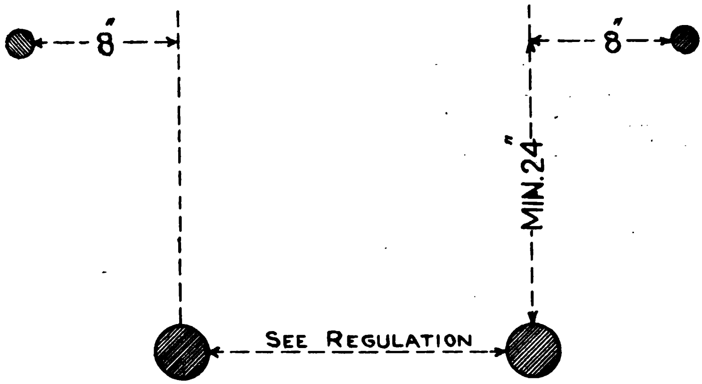
attached to the arms of telegraph poles. It is necessary that the spans should be short; and if required an additional pole or poles should be set.

(1) Where there is one trolley wire, two guard wires should be erected (Fig. 191).

(2) Where there are two trolley wires at a distance not exceeding 12 feet apart, two guard wires should be erected (Fig. 192).

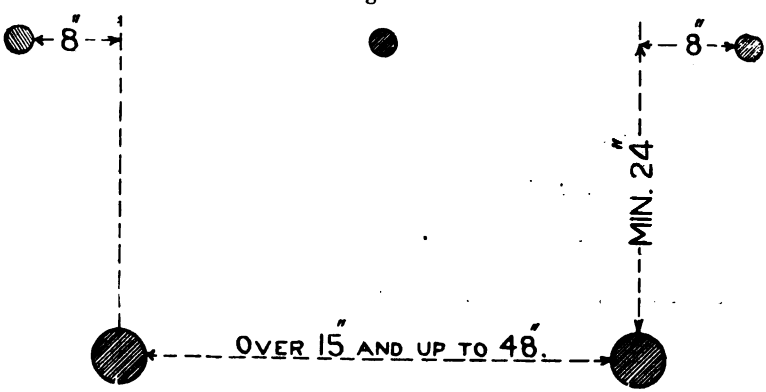
(3) In special cases, at junctions or curves, where parallel guard wiring would be complicated, two guard wires may be

Fig. 192.



GUARD WIRES OVER TWO TROLLEY WIRES (*a*).

Fig. 193.



GUARD WIRES OVER TWO TROLLEY WIRES (*b*).

so erected that a falling wire must fall on them before it can fall on the trolley wire.

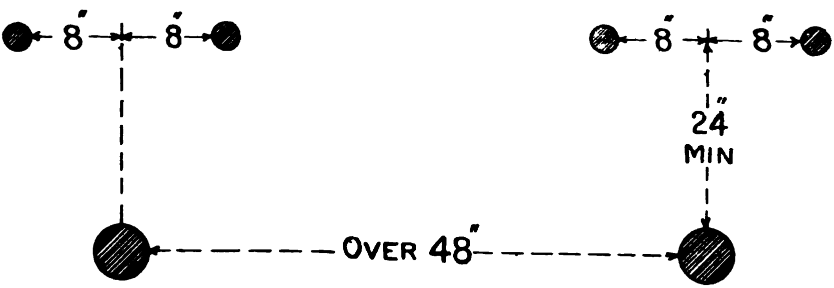
Class (b).—Wires weighing 100 *lbs. or more per mile.*

(4) Where there is only one trolley wire, two guard wires should be erected (Fig. 191).

(5) Where there are two trolley wires not more than 15 inches apart, two guard wires should be erected (Fig. 192).

(6) Where there are two trolley wires and the distance between them exceeds 15 inches, but does not exceed 48 inches, three guard wires should be erected (Fig. 193).

Fig. 194.



GUARD WIRES OVER TWO TROLLEY WIRES (*c*).

(7) Where the distance between the two trolley wires exceeds 48 inches, each trolley wire should be separately guarded (Fig. 194).

(8) It is desirable, where possible, to divert telegraph wires from above trolley junctions and trolley wire crossings, and undertakers should endeavour to make arrangements to that effect with the owners of telegraph wires.

Telegraph Wires parallel to Trolley Wires.

Classes (a) and (b).

(9) Where telegraph wires not crossing a trolley wire are liable to fall upon or to be blown on to a trolley wire, a guard

wire should be so erected that a falling wire must fall on the guard wire before it can fall on the trolley wire.

(10) When guard wires are attached to other supports than the trolley poles they should be connected with the rails at one point at least.

(11) When it is possible that a telegraph wire may fall on an arm or a stay, or a span wire, and so slide down on to a trolley wire, guard hooks should be provided.

General.

Minimum guarding requirements for Classes (*a*) and (*b*) are provided for in this memorandum, but in exceptional cases, such as in very exposed positions, or for unusually heavy telegraph wires, special precautions should be taken.

SPECIFICATION OF POSTS AND BRACKETS FOR OVERHEAD LINE CONSTRUCTION.

The Posts to be in number, of the design and dimensions shown upon the Drawing, and as specified herewith.

Each post to be made up of three sections of steel tubes. The various sections to overlap each other for a length of 18 inches, and to be shrunk together while hot and under pressure. Each joint to be covered by a neat close-fitting cast-iron ring, slipped over as shown. The longitudinal joints of the three sections to be set 120° apart in plan.

The posts to be of three different sizes, viz.:—"Light," "Medium," and "Heavy."

The light posts to be in number. To have the lower section 16 ft. long × 6 in. inside diameter × ·42 in. thick; the middle section 8 ft. 6 in. long × 5 in. inside diameter × ·29 in. thick; and the upper section 7 ft. 9 in. long × 4 in. inside diameter × ·23 in. thick.

The medium posts to be in number. To have the lower section 16 ft. long × 7 in. inside diameter × ·47 in. thick; the middle section 8 ft. 6 in. long × 6 in. inside diameter × ·38 in. thick; and the upper section 7 ft. 9 in. long × 5 in. inside diameter × ·30 in. thick.

The heavy posts to be in number. To have the lower section 16 ft. long × 8 in. inside diameter × ·60 in. thick; the middle section 8 ft. 6 in. long × 7 in. inside diameter × ·40 in. thick; and the upper section 7 ft. 9 in. long × 6 in. inside diameter × ·30 in. thick.

The posts to be as nearly round as possible, and perfectly straight and true when jointed. No post will be accepted if the difference between the maximum and minimum diameters

exceed $\frac{1}{8}$ in., or if the top of the post be more than $\frac{1}{4}$ in. out of truth.

A cast-iron base, arranged to slip over the lower section, and making a close fit at the neck, to be provided for each post. To be of the design and dimensions shown upon the Drawing. The lower section of the post to pass completely through the base.

The top of each post to be fitted with a neat cast-iron finial, properly secured, but arranged to be easily removed if required.

The Contractor will be required to submit an alternative price for Steel Taper Posts made in one piece, instead of the sectional posts. These posts to be two sizes, viz. :—"Light" and "Heavy."

The light posts to be in number, and 30 ft. 0 in. long over all. The lower portion for a length of 15 ft., to be 7 in. inside diameter × ·4375 in. thick. The upper portion to be tapered from 7 in. to 4 in. inside diameter × ·4375 in. thick, over the length of 15 feet.

The heavy posts to be in number, and 30 ft. 0 in. long over all. The lower portion for a length of 15 ft. to be 8 in. inside diameter × ·5625 in. thick. The upper portion to be tapered from 8 in. to 5 in. inside diameter × ·5625 in. thick, over the length of 15 feet.

Ornamental rings, finial and base of cast iron to be provided for each post, similar to those required for the sectional posts.

Bracket arms of hydraulic steel tube to be provided, of the various dimensions stated herewith, viz. :—

to be	long, for single arms.	
„	long, „ double „	(pairs).

The tubes to be 2 inches outside diameter, and not less than $\frac{1}{4}$ inch thick in any part. To be of the best hydraulic cold-drawn steel. Each single bracket arm to have a tail piece of

similar tubing, 1 ft. 6 in. long, and the pairs to be securely fastened into opposite halves of a substantial cast-iron clamp, for bolting to the posts, as shown upon the Drawing. The lengths of the bracket arms and tail pieces to be measured from the centre of the post.

Suitable clamps for the large posts to be included. The ends of the bracket arms and tail pieces to be stopped by neat, well-fitting, finials of cast iron, securely fixed.

Scroll work of wrought iron, $1\frac{1}{4}$ in. × $\frac{3}{8}$ in., with the necessary clamps and rings, to be provided for each post and bracket arm of the general design and dimensions shown upon the Drawing. The double bracket arms to have scroll work alike on both sides.

All the bracket arms included in this Contract to have a wrought-iron stay rod, $\frac{3}{4}$ in. diameter, properly secured to brace the arms.

of the posts, fixed where afterwards directed, each to have two insulated openings immediately above the bracket-arm clamp, to pass two feeder wires from the inside of the post along the outside of the arm. Each of these posts also to have suitable opening below the base, for the passage of the pipe containing the feeder cables.

The posts to be tested in the presence of the Engineer before acceptance, as follows, viz. :—

The Engineer to choose 10 % of the posts from the full number, light, medium, and heavy, and those selected to be dropped three times, butt end downwards, from a height of six feet, on to some solid substance, and must show no signs of telescoping, loosening of the joints, or other injury. This test to apply only to the sectional posts.

Each of the selected posts then to be laid horizontally, supported as a cantilever at a point 5 ft. 6 in. from the butt end, and loaded at a distance of 18 inches from the top end with a weight of 350 lbs. for the light posts, 700 lbs. for the medium posts, and 1,000 lbs. for the heavy posts. The temporary deflection at the extreme end must in no case exceed

six inches, and when the weight is removed the post must return to a perfectly true condition.

If required by the Engineer, the selected posts to be further tested, when supported as above, with a weight of 700 lbs. for the light posts, 1,200 lbs. for the medium posts, and 1,700 lbs. for the heavy posts, with a permanent deflection, when the weight is removed, not exceeding one half-inch.

In addition to the supply and delivery of the materials, the Contractor to include in his tender a price for the erection of the whole of the posts, etc., complete and ready for service, to the satisfaction of the Engineer, and in accordance with the drawings prepared by the Engineer, and deposited at the .

The Contractor to make all the necessary excavations for the posts, and care must be taken to disturb no more earth than is necessary.

The posts to be planted to a depth of 5 ft. 6 in. into the ground, set to the proper rake, and bedded in Portland cement concrete. If in soft ground, a large stone or flag to be placed at the bottom of the hole to receive the post. No excavated earth to be replaced, but the entire filling of the hole to be of cement concrete.

The Portland cement concrete to be composed of two parts of cement, three parts of sand, and six parts of broken stone. The cement to be Portland from an approved manufacturer. To be capable of bearing a tensile strain of 350 lbs. per square inch, after seven days' setting. The sand to be clean, sharp, screened, and washed. The stone to be clean, hard limestone or granite, broken to pass through a $1\frac{1}{2}$ inch ring. To be clean and free from dust.

The Contractor to replace all disturbed flags evenly in place, pending their being properly refixed by the Corporation; or he shall otherwise provide suitable filling to make the surface

smooth and even to the satisfaction of the Engineer. All surplus earth or materials to be immediately removed.

After the bases of the posts have been correctly set in position, the space between the neck and the post to be carefully caulked with lead.

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